A Novel Forwarding Scheme in HIPERLAN/2 for Enhanced Communication

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Certificate

This is to certify that the work contained in the thesis entitled "*A Novel Forwarding Scheme in HIPERLAN/2 for Enhanced Communication*", by *Major HS Vandra* has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Abstract

The multimedia communication over mobile communication networks demands higher transmission capacity and datarates every day. At the the same time the users expect better quality of service. The emerging Wireless LANs (WLAN) aim to satisfy these needs of the users. Therefore the project Broadband Radio Access Networks (BRAN) at the European Telecommunications Standards Institute(ETSI) is standardising a new generation of WLANs in the High PErformance Radio LAN (HIPERLAN) family. The HIPERLAN Type 2 which is currently being standardised will provide data rates up to 25 Mbps with mobility and full quality of service support.

The basic protocol stack and the scope of the HIPERLAN/2 standard will comprise the specification of a physical layer and a Data Link Control (DLC) Layer. The HIPERLAN/2 DLC Layer is composed of three major functional entities: the Medium Access Control (MAC) layer which applies a centrally controlled concept for the medium access, the Radio Link Control (RLC) protocol which defines all the DLC information which is transmitted via the radio interface and the Error Control(EC) protocol that is responsible for secure transmission of the user data.

In HIPERLAN/2 there can be scenarios when a user is beyond the acceptable range of an Access Point (AP). This can result from heavy attenuation on the direct link either due to increased distance or due to impairments in the radio path. For example the former can often arise due to the user mobility and the latter can be encountered while attempting to operate from another office in a complex. This thesis is aimed to tackle such scenarios which might be temporary or deliberate. In the thesis the HIPERLAN/2 MAC protocol is extended to function as a *forwarder*. The purpose of the forwarder is to forward traffic to remote users, which are unable to communicate with the AP directly.

In this thesis forwarding for HIPERLAN/2 is based on a time sharing concept, wherein the forwarder shares the MAC Frame to forward traffic to the remote user. The concept is implemented into HIPERLAN/2 simulator developed in the Specification and Description Language (SDL). The theoretical analysis done is verified through simulations. A network was setup with a AP, forwarder and a remote mobile user in the simulator and the simulating scenario was made close to the real environment by the use of different software tools. The results, conclusions drawn and a reference to the future work have been included in the thesis.

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List of Abbreviations

ACF	Association Control Function	ACH	Access feedback CHannel
ANSI	American National Standards Institute	AP	Access Point
APC	Access Point Controller	APT	Access Point Transceiver
ARQ	Automatic Repeat reQuest	ASCH	Association Control CHannel
ATM	Asynchronous Transfer Mode	BCH	Broadcast Channel
BCCH	Broadcast Control CHannel	BER	Bit Error Rate
BPSK	Binary PSK	B-ISDN	Broadband Integrated Services Digital Network
BRAN	Broadband Radio Access Network	BS	Base Station
CBR	Constant Bit Rate	CCH	Control CHannel
CCITT	Comité Consultatif International de Télégraphique et Téléphonique	CDF	Complementary Distribution Function
CL	Convergence Layer	CLR	Cell Loss Ratio
CNCL	Communication Networks Class Library	CRC	Cyclic Redundancy Check
DCC	DLC user Connection Control	DCCH	Dedicated Control CHannel
DLC	Data Link Control	DLCC	DLC Connection
DLCH	DownLink CHannel	DUC	DLC User Connection
EC	Error Control	ETSI	European Telecommunication Standards Institute
FCH	Frame CHannel	FCCH	Frame Control CHannel
FEC	Forward Error Correction	FFT	Fast Fourier Transformation
F-BCH	Forwarding Broadcast CHannel	F-DL	Forwarding DownLink
F-FCH	Forwarding Frame CHannel	F-LCH	Forwarding Long CHannel
FMT	Forwarding Mobile Terminal	F-RACH	Forwarding Random Access CHannel
F-SCH	Forwarding Short CHannel	F-UL	Forwarding UpLink
GBN	Go-Back-N	GMM	Global Multimedia Mobility
GSM	Global System for Mobile Communication	HARQ	Hybrid ARQ
HDLC	High-level Data Link Control procedure	HIPERLAN	HIgh PErformance Radio LAN
ICI	Interface Control Information	ID	IDentity number
IEEE	Institute of Electrical and Electronics Engineers	IFFT	Inverse Fast Fourier Transformation
IP	Internet Protocol	ISDN	Integrated Services Digital Network
ISO	International Standardization Organization	LAN	Local Area Network

LCH	Long CHannel	LLC	Logical Link Control
LCCH	Link Control CHannel	MAC	Medium Access Control
MBS	Maximum Burst Size	MT	Mobile Terminal
OFDM	Orthogonal Frequency Division Multiplexing	OSI	Open Systems Interconnection
PCI	Protocol Control Information	PDU	Protocol Data Unit
PER	Packet Error Rate	PHL	PHysical Layer
PLR	Packet Loss Ratio	PSK	Phase Shift Keying
PT	Payload Type	QAM	Quadrature Amplitude Modulation
QoS	Quality of Service	QPSK	Quadrature PSK
RACH	Random Access CHannel	RCH	Random CHannel
REJ	REJect	RMT	Remote Mobile Terminal
RN	Request Number	RNR	Receive Not Ready
RLC	Radio Link Control	RR	Resource Request
RRC	Radio Resource Control	SAP	Service Access Point
SAR	Segmentation And Reassembly	SBCH	Slow Broadcast Channel
SCH	Short CHannel	SDU	Service Data Unit
SN	Sequence Number	SR	Selective Repeat
SREJ	Selective REJect	SF	(MAC) Sub Frame
TCP	Transmission Control Protocol	TDD	Time Division Duplexing
TDMA	Time Division Multiple Access	UBR	Unspecified Bit Rate
UDCH	User Data Channel	ULCH	Up Link CHannel
UMTS	Universal Mobile Telecommunication System	VBR	Variable Bit Rate
VC	Virtual Connection	WLAN	Wireless LAN

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Chapter 1

Introduction

Massive growth in the wide spectrum usage in mobile communications area has been witnessed towards the end of 20th century. The human urge for *more and more* services and systems are the strong motivating forces that drive the telecommunication research engineers and the industry to innovate in this field. The technological advances can be gauzed by looking at successfully established systems such as the Global System for Mobile Communication (GSM900), the Digital Cellular System (DCS1800) and the Digital Enhanced Cordless Telephone (DECT).

When using communication networks for data transmission and multimedia communication, it is important to complement the existing circuit switched communication with the packet switched handling of traffic. In GSM, this is done by the General Packet Radio Service (GRPS), which will be available in the near future. Additional high datarate is partially supported by GRPS as it offers a peak datarate of 64 Kbps, but this does not enhance the datarate of a whole GSM cell. This will be done by the future GSM technologies Enhanced GSM (EGSM) and Enhanced GRPS (EGRPS).

The 3rd generation mobile system Universal Mobile Telecommunication System (UMTS), envisages to support both the circuit and the packet switched communication upto 2 Mbps.

Thirsty of multimedia applications like video confrencing even these datarates will not be sufficient. The problem is addressed by a new generation of *wireless LANs* (WLAN). These WLANs will support services already known in the computer networking area. These services are complemented with a number of originally developed features for wireless telecommunication networks like guaranteed Quality of Service (QoS) and mobility support.

To meet all these requirements, the European Telecommunications Standards Institute (ETSI) set up the Broadband Radio Access Networks (BRAN) project. The project will make available specifications for the access to wired networks in private as well as in public context and the systems are supposed to offer bit rates upto 155 Mbps.

1.1 Objectives

One of the new standards inside the BRAN Project is the HIPERLAN/2 standard. It will offer access to Internet Protocol (IP), Asynchronous Transfer Mode (ATM) and UMTS based core networks and will offer a data rate of up to 25 Mbps. The standardisation work is expected to be completed by the first quarter of 2000. The work on HIPERLAN/2 at the Aachen University of Technology (RWTH) has contributed towards this standardisation. A HIPERLAN/2 simulator is being developed at the RWTH for the purpose of simulations and evaluations. The models of physical layer, Medium Access Control (MAC) layer and the Radio Link Control (RLC) protocol are ready and at present the Error Control protocol and the integration of the simulator is in the final stages. As a collaborative work with IIT Kanpur, study carried out in this thesis was aimed to look into the prospects of extending the MAC protocol to function as a *forwarder* for HIPERLAN/2. There can be situations when a Mobile Terminal (MT) is unable to communicate with an Access Point (AP) directly either due to large distance between an AP and a MT or due to high attenuation because of obstacles in the radio line of sight. The task of the forwarder will be to make this communication possible by forwarding data in either direction. This extension of the MAC protocol to function as a forwarder is not included in the first phase of HIPERLAN/2 standardisation at the ETSI. The field is still wide open.

1.2 Prospects

We present our work in this study as follows.

Chapter 2 gives an overview of the systems being standardised in the BRAN project. This is followed by an introduction to the HIPERLAN/2 system, explanation of the HIPERLAN/2 service model and a brief look into the physical and the Data Link Control (DLC) layer. The HIPERLAN/2 simulator is written in the Specification and Description Language (SDL) and Chapter 3 introduces the SDL language. Chapter 4 highlights the concepts of forwarding and various options available to implement forwarding in HIPERLAN/2. Proceeding with one of the most suitable options, Chapter 6 presents the details of implementation of the forwarder in the HIPERLAN/2 simulator. Theoretical analysis has been done in Chapter 5 and the verification of these theoretical results through simulations and performance analysis follows in Chapter 7. Finally Chapter 8 summarises the results. The aspects to be studied in the future have been suggested.

Chapter 2

HIPERLAN/2

Massive growth has been seen in the wireless and mobile communications in the recent years. The emergence of multimedia applications, high speed Internet access and the deregulation of the telecommunications industry are the key drivers towards a new demand for the radio based broadband access networks. The European Telecommunications Standardisation Institute (ETSI) took up this demand and fielded the Broadband Radio Access Networks (BRAN) project which will release standards for the members, HIPERLANs 1 and 2, HIPERACCESS and HIPERLINK of the HIPERLAN family. The system specified in the BRAN project will provide fixed public and private wireless networks offering bit rates up to 155 Mbps. BRAN will standardize only the radio access network and some of the convergence layer functions to the different core networks of TCP/IP, UMTS, ATM and the IEEE 1394 (Figure 2.1). The core network specific functions like user provisions and user profile handling will be left to the corresponding fora e.g. ATM Forum or the Internet Engineering Task Force (IETF).

The usage of wireless techniques in the scope of local networks is characterized through the following properties:

- Small costs for installation and service,
- High flexibility,
- No overlap with existing wired networks.

Wireless access networks are independent from existing wired infrastructure, although they may operate as extensions to the wired networks. Wireless networks can be setup quickly as no digging for cabling is needed. But before taking advantages out of these benefits of wireless access networks, a number of challenges have to be overcome. Some of these issues relate to:

- Changing transmission quality in radio cells

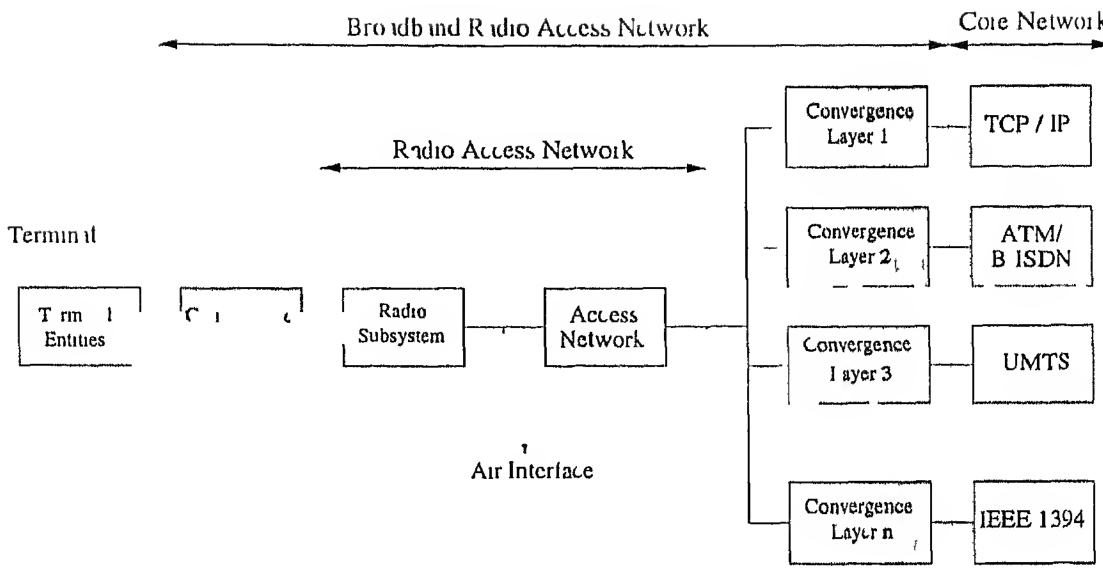


Figure 2 1 HIPERLAN family reference model

- Handling of distributed media

2 1 HIPERLAN Family

In 1997, ETSI specified the first wireless access network the High PErformance Radio Local Area Network type 1 (HIPERLAN/1) [13] It provides high speed radio local area network communications that are compatible with wired LANs based on the Ethernet standard ISO 8802 3 [3] and the Token Ring standard ISO 8802 5 [4] HIPERLAN/1 operates in the 5 GHz band with a maximal data rate of 20 Mbps and supports restricted user mobility within the local service area only

After acquisition of the functional specifications of HIPERLAN/1, ETSI is developing three further standards in the project BRAN (Figure 2 2)

- **HIPERLAN/2**
  This short range variant (up to 100 m) is intended for complementary access mechanism for UMTS systems as well as for private use as a wireless LAN type system It will offer high speed access (typical data rate 25 Mbps) to a variety of networks including the IP based networks, ATM networks and the UMTS core networks Spectrum has been allocated in the 5 GHz range A system overview is given in [18]

- **HIPERACCES**
  This long range variant is point to multipoint, high speed access (typical data rate 25 Mbps) by residential and small business users to a wide variety of networks including

the UMTS, ATM and IP based networks (HIPERLAN/2 might be used for distribution within premises) [11] (see Figure 2 2)

- HIPERLINK

  This variant provides short range very high speed interconnection of HIPERLANs and HIPERACCESS up to 155 Mbps over distances up to 150 m Frequency allocation for HIPERLINK is in the 17 GHz range

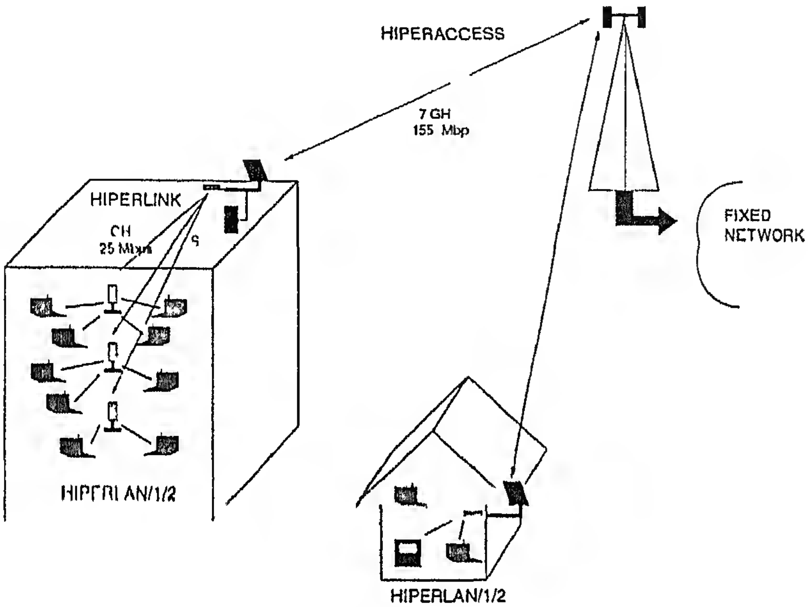


Figure 2 2 ETSI BRAN Systems Broadband Radio Access

The specification of the protocols and interfaces for HIPERLAN/2 and HIPERACCESS has current priority in the work of BRAN Project Stable draft functional specifications are expected in the first and the second quarter of 2000 for HIPERLAN/2 and HIPERACCESS respectively

2 2 HIPERLAN/2 System Architecture

Figure 2 3 illustrates the schematic structure of a cellular HIPERLAN/2 system An Access Point (AP) which is typically connected to a core network can be subdivided into an Access Point Controller (APC) and upto sixteen Access Point Transceivers (APTs) An APT, characterized by its frequency, covers a certain area called radio cell The APC is responsible for the management of the APTs

The HIPERLAN/2 network provides wireless access to wired networks for users of the Mobile Terminals (MTs) These might be inside buildings, outside free terrain or in prox

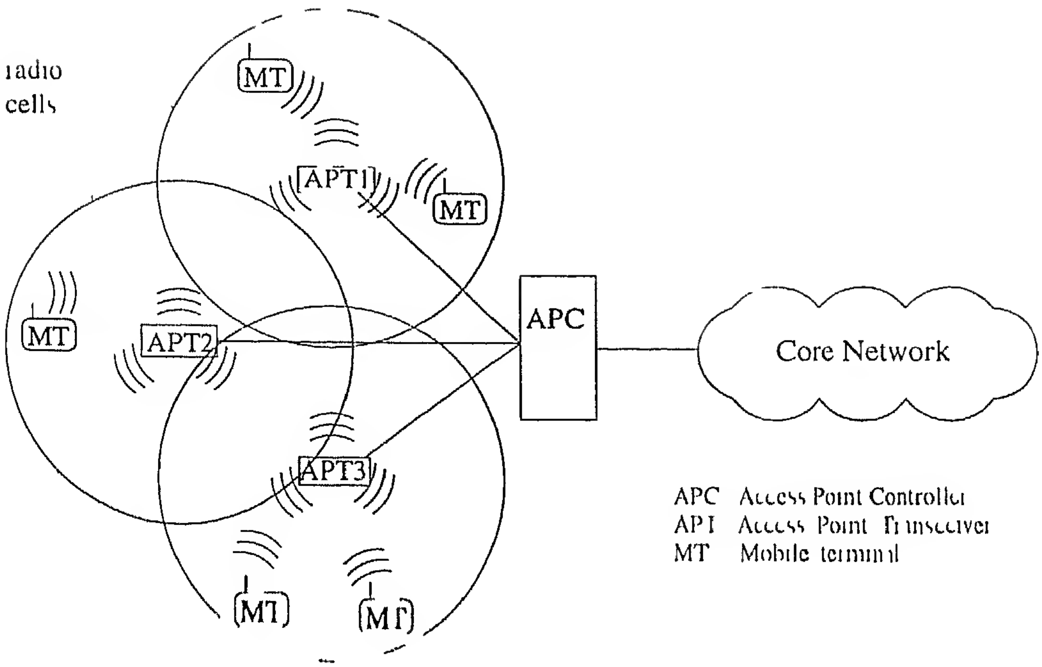


Figure 2.3 Structure of a cellular HIPERLAN/2 system

imity to buildings. Inside a radio cell each associated MT is represented by a unique Identification Number (Mobile ID).

2.3 HIPERLAN/2 Features

The general features of the HIPERLAN/2 technology can be summarized in the following list

- High speed transmission
- Quasi Connection orientation
- Quality of Service (QoS) support
- Automatic frequency allocation
- Security support
- Mobility support
- Network and application independency
- Power saving

A short description of each of these features is given below

- **High Speed Transmission**
  HIPERLAN/2 has transmission rate which at the physical layer extends up to 54 Mbps and provides a user bit rate of up to 25 Mbps To achieve this HIPERLAN/2 makes use of a modulation method called Orthogonal Frequency Division Multiplexing (OFDM) for transmission [27] OFDM is very efficient in time dispersive environments e g within offices where the transmitted radio signals are reflected from many points leading to different propagation delays before they reach the receiver Above the physical layer the Medium Access Control (MAC) protocol provides dynamic Time Division Duplex (TDD) access scheme to allow efficient utilization of the radio resources

- **Quasi Connection Orientation**
  In HIPERLAN/2 data is transmitted on connections between the MT and the AP, that have been established prior to the transmission using signalling functions of the HIPERLAN/2 control plane There are two types of connections point to point and point to multipoint Point to point connections are bidirectional whereas point to multipoint are unidirectional in the direction towards the MTs In addition there is also a dedicated broadcast channel (BCCH) which is evaluated by all the MTs in a radio cell

- **QoS Support**
  The quasi connection oriented nature of HIPERLAN/2 is a prerequisite for the support for QoS Each connection can be assigned a specific QoS for instance in terms of bandwidth delay delay variation bit error rate etc In an environment where the connection characteristics are not available QoS is supported by assigning a priority level relative to other connections This QoS support in combination with the high transmission rate provides simultaneous transmission of many different types of data streams, e g video, voice and data

- **Automatic Frequency Allocation**
  In HIPERLAN/2 there is no need for manual frequency planning as in cellular networks like GSM The radio base stations, which are called APs in HIPERLAN/2, have a built in support for automatically selecting an appropriate radio channel for transmission within each AP s coverage area An AP listens to neighbouring APs as well as to other radio sources in the environment and selects appropriate radio channel based on both radio channels already used by other APs and to minimize interference with other radio cells

- **Security Support**
  HIPERLAN/2 supports authentication and encryption With authentication both

the AP and the MT can authenticate each other to ensure authorized access to the network (from the AP's point of view) or to ensure access to a valid network operator (from the MT's point of view). Authentication relies on the existence of a supporting function, such as directory service, but which is outside the scope of HIPERLAN/2. The user traffic on established connections can be encrypted to protect against (for instance) eavesdropping and man in middle attacks.

- Mobility Support

  The MT uses the AP with the best radio signal performance as measured by the signal to noise ratio and the Packet Error Rate (PER). Thus, as the user moves around with the MT, the MT may detect that there is an alternative AP with better radio transmission performance than the AP which the MT is currently associated to. The MT will then initiate a hand over to this AP. All established connections will be moved to this new AP. The MT stays associated to the HIPERLAN/2 network and can continue its communication. During a handover some packet loss may occur. If an MT moves out of radio coverage for a certain time, the MT may loose its association to the HIPERLAN/2 network resulting in the release of all connections. In such a case a Forwarding Mobile Terminal (FMT) can be used to forward data to these MTs.

- Network & Application Independency

  HIPERLAN/2 protocol stack has a flexible architecture for easy adaptation and integration with a variety of fixed networks. A HIPERLAN/2 network can for instance be used as the *last hop* wireless segment of a switched Ethernet, but it may also be used in other configurations, e.g. as an access network to the 3rd generation cellular networks. All applications which today run over a fixed infrastructure can also run over a HIPERLAN/2 network.

- Power Saving

  In HIPERLAN/2 the mechanism to allow MTs to save power is based on MT initiated negotiation of sleep periods. The MT may at any time request the AP to enter a low power state (specific per MT) and requests for a specific sleep period. At the expiration of the negotiated sleep period, the MT searches for the presence of any wake up indication from the AP. If no wake up indication is received, the MT reverts back to its low power state for the next sleep period. An AP will delay any pending data to a MT until the corresponding sleep period expires. Different sleep periods are supported to allow for either short latency requirement or low power requirement.

2.4 Example Applications

HIPERLAN/2 can be used in congested areas like mentioned below. Besides the advantages of HIPERLAN/2 it also saves the place and efforts for wire based installations.

- **Corporate LAN**

  Consider a corporate network built around ethernet LAN and IP routers. A HIPERLAN/2 network is used as the last segment between the MTs and the network/LAN. The HIPERLAN/2 network supports mobility within the same LAN/subnet. Moving between subnets implies IP mobility above HIPERLAN/2 layers, which is transparent to the IP network.

- **Hot Spots**

  HIPERLAN/2 networks can be deployed at hot spot areas, e.g. airports, hotels, etc., to enable an easy way of offering remote access and Internet services to business people. An access server to which the HIPERLAN/2 network is connected can route a connection request for a point to point connection either to a corporate network (possibly via a preferred Internet Service Provider (ISP)) or perhaps to an ISP for an Internet access.

- **Access to 3rd Generation Cellular Networks**

  HIPERLAN/2 can be used as an alternative access technology to a 3rd generation cellular core network. One may think of the possibility to cover hot spots and city areas with HIPERLAN/2 and the wide area with W-CDMA technology. The user can benefit from a high performance network wherever it is feasible to deploy HIPERLAN/2 and use W-CDMA elsewhere. The core network provides the user, with automatic and seamless handover between the different types of access networks as the user moves between these access networks.

- **Home Network**

  Another example of HIPERLAN/2 is to use the technology in a home environment to create a wireless infrastructure for home devices, e.g. home PCs, VCRs, cameras, printers, etc. The high throughput and QoS features of HIPERLAN/2 supports the transmission of video streams in conjunction with the datacom applications. The AP may in this case include an uplink to the public network, e.g. an ADSL or cable modem for communications with outside world.

2.5 HIPERLAN/2 Service Model

The structure of the HIPERLAN/2 reference model is based on the Open System Interconnections (OSI) reference model of the International Standardization Organisation (ISO) [21] [32]. In the following section the basis of the ISO/OSI reference model will be described. In section 2.5.2, the HIPERLAN/2 service model will be presented in detail.

2.5.1 ISO/OSI Reference Model

Since the exchange of information between communicating partners is complex in structure, the entire communications process has universally been standardized and organised into individual well defined hierarchical layers. Each layer offers service to the layer above it. These services are implemented by the passing of information between the peer entities of respective layers of the communicating systems using protocols. Therefore each layer communicates only with the layer immediately above or below it. The higher ranking layer is referred to as the *service user* and the lower ranking layer as the *service provider*. A layer will exchange Protocol Data Units (PDUs) with the layer below in order to communicate with its peer entity. Figure 2.4 illustrates the mapping of PDUs from one layer to the next one.

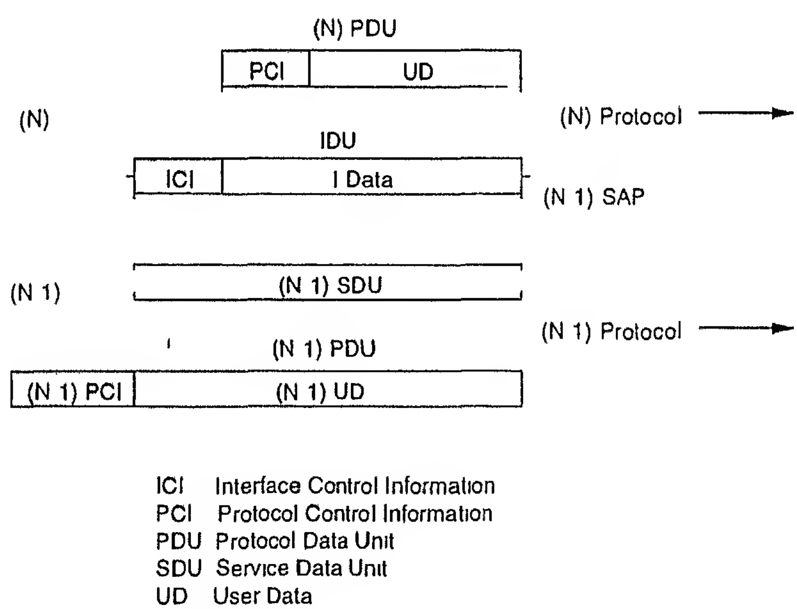


Figure 2.4: Communication in the ISO/OSI Reference Model

A PDU consists of Protocol Control Information (PCI) and a Service Data Unit (SDU). The SDU consists of the user data and the PCI is the information necessary for the peer entity to process this SDU. The interfaces between the two layers is called Service Access Point (SAP). At these SAPs the PDUs will be mapped into an Interface Data Unit (IDU) for the layer underlying. An IDU consists of an Interface Control Information (ICI) and the

PDU (see Figure 2.4). The service user processes a PDU based on the information contained in the ICI. The structure of the layers makes it easier for protocols to be implemented and standardized. The hierarchical model facilitates communication between developers, suppliers and the users of communications systems. If a change is undertaken in one of the layers, it does not affect the others.

The ISO specified a generally accepted layered model called ISO/OSI Reference Model (Figure 2.5). This model is referred by almost all communications systems in use today.

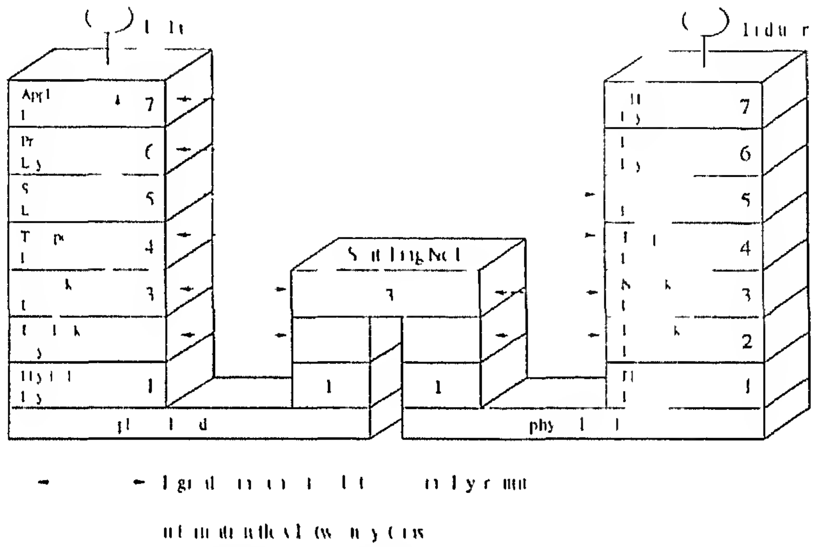


Figure 2.5 ISO/OSI Reference Model

Each layer of the OSI model has precisely defined functions. The boundaries between the individual layers have been established to differentiate the various service levels inside a communication system. Each layer represents a new level of abstraction of the layer below. To keep the number of layers and interfaces to a minimum, several different functions have been grouped.

The following is a brief description of different tasks of seven layers of the OSI Reference Model.

- **Layer 1 Physical Layer**

  The physical layer is also called the bit transmission layer. It provides the basis for communication and describes the transmission of bits over a physical communication channel. It defines the electrical and mechanical characteristics, e.g. standardised plugs, synchronized transmission over cables or radio channels, synchronising techniques, signal coding, and signal levels for the interfaces.

- **Layer 2 Data Link Layer**

  The task of the data link layer is to interpret the bit stream of layer 1 as a sequence of data blocks and to provide an error free transmission for the network layer. Error detection or correction codes are used to protect data against transmission errors.

Thus, for example, systematic redundancy that is used at the receiving side for error detection is added by the transmitter to the data which is transmitted in blocks called frames. These frames are transmitted sequentially between peer entities of layer 2. If a transmission error is detected, then an acknowledgement mechanism initiates a retransmission of the block and guarantees that the sequence will be maintained. The data link layer adds special bit patterns to the start and the end of blocks to ensure their recognition. Because of flow control on both sides, the logical channel can be used individually by the communicating partner entities. Layer 2 contains the access protocol for the medium and functions for call set-up and termination with regard to the operated link.

- **Layer 3 — Network Layer**

  The network layer is responsible for setting up, operation and termination of network connections between open systems. In particular, this includes routing, address interpretation and optimal path selection when a connection is established or during a connection. Layer 3 also has the task of multiplexing connections onto the channels of the individual subnets between the network nodes.

- **Layer 4 — Transport Layer**

  The transport layer has responsibility for end to end data transport. It controls the beginning and the end of a data communication, carries out the segmentation and reassembly of messages and controls data flow. Error handling and data security, co-ordination between logical and physical equipment addresses and optimization of information transport paths also fall within the range of this layer's tasks. The transport layer represents the connecting link between the network dependent layers 1–3 and the network independent overlaid layers 5–7 and provides the higher layers with a network independent interface. The transport layer provides a service with a given quality to the communicating application processes regardless of the type of network used.

- **Layer 5 — Session Layer**

  The session layer controls communication between participating terminals and contains functions for exchange of terminal identification, establishing the form of data exchange, dialogue management, tariff accounting and notification, resetting to an initialized logical checkpoint after dialogue errors have occurred and dialogue synchronisation.

- **Layer 6 — Presentation Layer**

  The presentation layer offers services to the application layer that transform data structures into a standard format for transmission agreed upon and recognised by all

partners. It also provide services such as data compression as well as encryption to increase confidentiality and authenticity of the data.

- **Layer 7 Application Layer**
  The application layer forms the interface to the user or an application process needing communication support. It contains standard services for supporting data transmission between user processes (e.g. file transfer), providing distributed database access, allowing a process to be run on different computers, controlling and managing distributed systems.

2.5.2 HIPERLAN/2 Service Model Layers

The HIPERLAN/2 service model is based on the OSI/ISO Reference model. The basic protocol stack of the HIPERLAN/2 standard is shown in Figure 2.6. It comprises the specification of a physical layer and a DLC layer for both the MTs and the APs. One of the major properties of HIPERLAN/2 is the support of various network types on top of the DLC layer. Currently packet networks (IP, Ethernet), ATM and UMTS are being considered. These are connected to the DLC layer by the network Convergence Layers (CL) (Section 2.5.3) which performs the adaptation of the packet formats to the requirement of the DLC layer. In case of higher layers other than ATM, the CL contains a segmentation and reassembly function (SAR). The physical layer (PHY) provides the basic transport functions for the DLC PDUs. Details on this layer can be found in [17]. The DLC layer can be subdivided into two parts: the control plane and the user plane. Details of the DLC layer are given in [16]. On the user plane side, the data transport function is fed with user data packets from the higher layers via the User Service Access Point (U-SAP). This part contains the Error Control (EC) (Section 2.5.2) which works on basis of an Automatic Repeat Request (ARQ) protocol. The DLC protocol operates connection oriented and provides multiple connection end points in the U-SAP. The control plane consists of the Radio Link Control Protocol (RLC) (Section 2.5.2) which includes the DLC Connection Control (DCC), the Radio Resource Control (RRC) and the Association Control Functions (ACF). Both planes access the physical medium via the Medium Access Control (MAC) sublayer (Section 2.5.2).

In the following sections, the individual layers of the HIPERLAN/2 service model and protocols of the DLC layer are explained.

Physical Layer

HIPERLAN/2 systems are intended to be operated as private or public systems in the 5 GHz frequency range. Table 2.1 shows the two frequency bands and the power limits allocated for HIPERLAN/2.

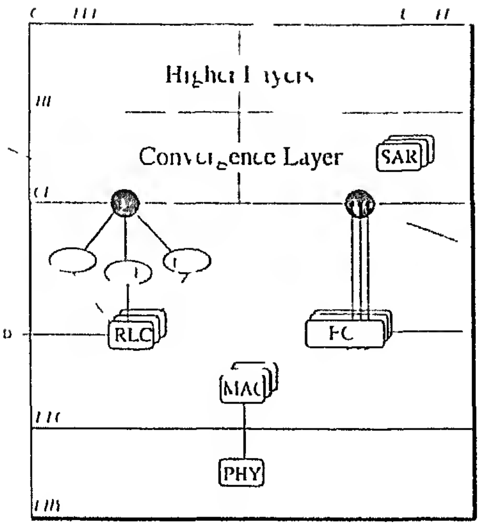


Figure 2.6: Service Model of HIPERLAN/2

Table 2.1: Frequency Range

Frequency Range	RF Power Limit	Comments
5.15 - 5.35 GHz	200 mW mean EIRP	indoor use only
5.47 - 5.725 GHz	1 W mean EIRP	indoor and outdoor use

But these frequency bands are not attributed exclusively to HIPERLAN/2 systems who will have to be able to share it with other radio subsystems like radar systems, some of which might be mobile. This type of sharing requires dynamic adaptation called Dynamic Frequency Selection (DFS) [30]. For the modulation scheme OFDM has been selected due to its good performance on dispersive channels. A comparison with single carrier modulation showing the superiority of OFDM for HIPERLAN/2 systems is presented in [31]. The channel raster is 20 MHz. In order to avoid unwanted frequency products in implementations the sampling frequency is also chosen equal to 20MHz at the output of a typically used 64 point *Inverse Fast Fourier Transformation* (IFFT) [27]. The obtained subcarrier spacing is 312.5 kHz. In order to facilitate implementation of filters and to achieve sufficient adjacent channel suppression, 52 subcarriers are used per channel. 48 subcarriers carry the actual data and 4 subcarriers are pilots which facilitate phase tracking for coherent demodulation. Further detailed investigations can be found in [29]. The shortest transmitted unit is an OFDM Symbol. It has a duration of 3.2 μs and possesses an additional protection time of 800 ns. Thus an OFDM symbol has a total length of 4 μs. Table 2.2 summarises the basic properties of the physical layer.

A key feature of the physical layer is to provide several physical layer modes with different coding and modulation schemes which may be selected by link adaptation mechanisms [22]. BPSK, QPSK, 16QAM are mandatory subcarrier modulation schemes whereas 64QAM can be used in an optional mode. Forward Error Control (FEC) is performed by a convo

can be used in an optional mode. Forward Error Control (FEC) is performed by a convolutional code of rate 1/2 and constraint length seven. The further code rates 9/16 and 3/4 are obtained by puncturing. According to the chosen modulation and code rate different transmission rates result as shown in Table 2.3.

Table 2.2 Basic parameters of the PHY layer

channel spacing and system clock	20 MHz
FFT length	64
number of used subcarriers	52
number of used data carriers	48
number of used pilot carriers	4
modulation scheme on subcarriers	refer Table 2.3
demodulation	coherent
data phase length	3.2 μs
guard interval length	800 ns
Total OFDM Symbol length	4 μs
channel coding	convolutional code constraint length 7
interleaving	per OFDM symbol

Table 2.3 Modulation and Code Rate dependant transmission rates

Modulation	Code rate	capacity of one OFDM Symbols	Transmission rate
BPSK	1/2	3 byte	6 Mbps
BPSK	3/4	4.5 byte	9 Mbps
QPSK	1/2	6 byte	12 Mbps
QPSK	3/4	9 byte	18 Mbps
16 QAM	9/16	13.5 byte	27 Mbps
16-QAM	3/4	18 byte	36 Mbps
64-QAM (optional)	3/4	27 byte	54 Mbps

The physical layer of HIPERLAN/2 will have to be well harmonised with the ones that are currently being developed for the US and the Japanese market. In the US, the high speed physical layer will be an extension to the IEEE 802.11 [2], which will re use the MAC layer already defined. The corrosponding system in Japan will have three different upper layer protocols for three different services but it will be based on a common physical layer. The frequency allocation of these two systems is slightly different to the one for HIPERLAN/2 (Table 2.4).

Data Link Control Layer

The Data Link Control(DLC) layer of HIPERLAN/2 is subdivided into a User Plane and a Control Plane (Figure 2.6). The control plane consists of

- Radio Link Control(RLC)

whereas the user plane includes

- Medium Access Control (MAC)
- Error Control (EC)

Table 2.4: Frequency allocation for wireless LANs in US and Japan

Country	Frequency Range
US	5.15 – 5.35 GHz and 5.725 – 5.825 GHz
Japan	5.15 – 5.25 GHz

Medium Access Control Protocol

The Medium Access Control(MAC) protocol is the protocol used for organising access to and transmission of data on the medium (radio link). The control is centralised to the AP which informs the MT at which point in time in the MAC frame they are allowed to transmit their data. The length and the start point varies and is dependant upon the Resource Requests (RR) from each of the MTs. The radio interface is based on Time Division Duplex (TDD) and the dynamic Time Division Multiple Access (TDMA) i.e. the time slotted structure allows simultaneous communication in both downlink and uplink within the same frame. This slotted structure is called MAC Frame (MF) in HIPERLAN/2. The time slots are grouped to MFs of constant length of 2ms. Thus a MF consists of 500 OFDM symbols. The assignment of resources for the individual MTs and their connections is not static but may change dynamically from one MAC frame to the other. Each MAC frame consists of Four phases i.e. Broadcast, Downlink, Uplink and Random Access Phase. Each of these phases have been explained in the succeeding paragraphs.

- **Broadcast Phase** (BC Phase)

  The BC phase carries the Broadcast Control CHannel(BCCH), the Frame Control CHannel (FCCH) and the Access Feedback Channel (ACH).

– **BCCH**

The BCCH (downlink only) contains control information (see Figure 2.7) through the Broadcast CHannel (BCH) PDU that is sent in each MF and reaches all MTs. The BCCH provides information about transmission power levels, starting point and length of the Frame CHannel (FCH) and the Random CHannel (RCH), wake up indicator and identifiers for identifying both the HIPERLAN/2 network and the AP. It is 15 bytes in length and is always transmitted using the most robust modulation scheme available i.e. BPSK 1/2.

Frame Counter	4 bit
NET ID	4 bit
AP ID	8 bit
Antenna ID	3 bit
AP TX Level	4 bit
AP RX UL level	3 bit
Pointer to FCCH	12 bit
Length FCCH	4 bit
Phy Mode of FCCH	2 bit
Pointer to RACH UP	13 bit
Length of RACH UP	5 bit
Guard Space between RCH	2 bit
AP traffic Load	2 bit
SBCH Indicator	1 bit
Wake UP indicator	1 bit
Uplink preamble	1 bit
Future Use	2 bit
CRC	24 bit

Figure 2.7 BCCH

– **FCCH**

The FCCH (downlink only) contains an exact description of how the resources have been allocated (and thus granted) within the current MAC frame in the Downlink (DL) and the Uplink (UL) phase and for the RCH (Figure 2.8. The FCCH includes number of FCH PDUs and the length of each FCH is 27 bytes. This includes 8 bytes each for three Information Elements (IE) and 3 bytes of

CRC 24. Thus the length of FCCH is a multiple of 27 bytes. One IE carries information for one User Connection only and three IEs constitute a FCH PDU. The IE gives the start slot, length and the modulation scheme to be used for the user connection. There will be separate IEs for DL and UL phase for each user connection.

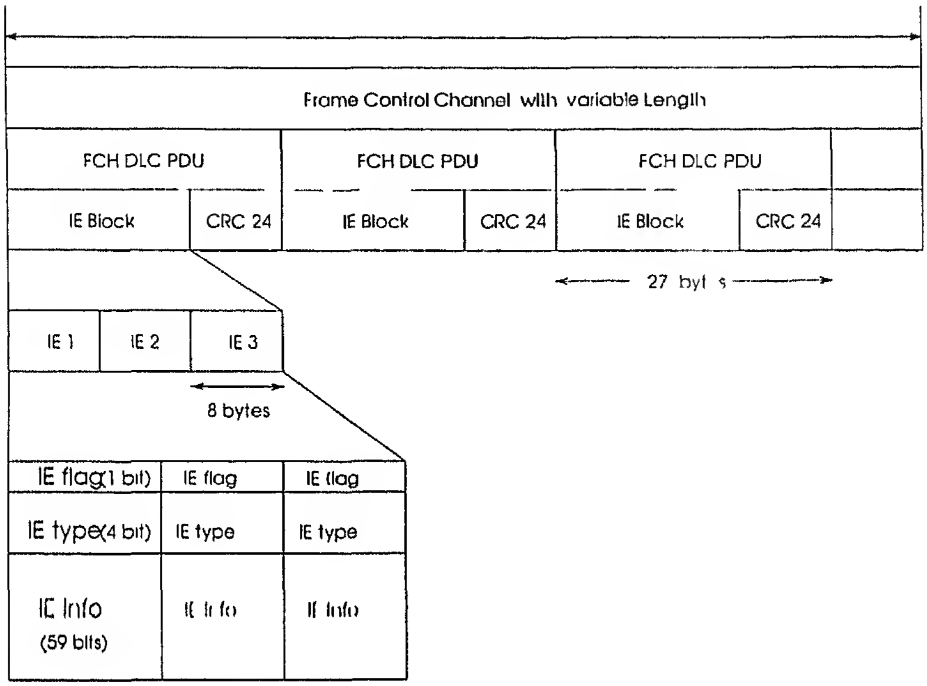


Figure 2.8: FCCH

– **ACH**

The ACH (downlink only) conveys information on previous access attempts made in the RCH.

- **Downlink Phase**

  The DL phase carries user specific control information and the user data transmitted from an AP to a dedicated MT.

- **Uplink Phase**

  The UL phase carries control and user data from the MTs to the AP.

- **Random Access CHannel(RACH)**

  MTs that do not have capacity allocated in the UL phase use the RACH for transmission of control information. Non-associated MTs get in first contact with an AP via the RACH. This channel is also used by MTs performing handover to have their connections switched over to a new AP. For the RACH the principle of *Slotted ALOHA Algorithm* [8] [32] with a binary exponential back off strategy is applied [9] [10].

Each of these phases contain logical channels that are mapped to physical transport channels. The distinction between physical and logical channels enables a simple exchange of the lower layers keeping the interface to the higher layers and vice versa. Figures 2.9 and 2.10 illustrate the phases with logical channels and the corresponding physical channels.

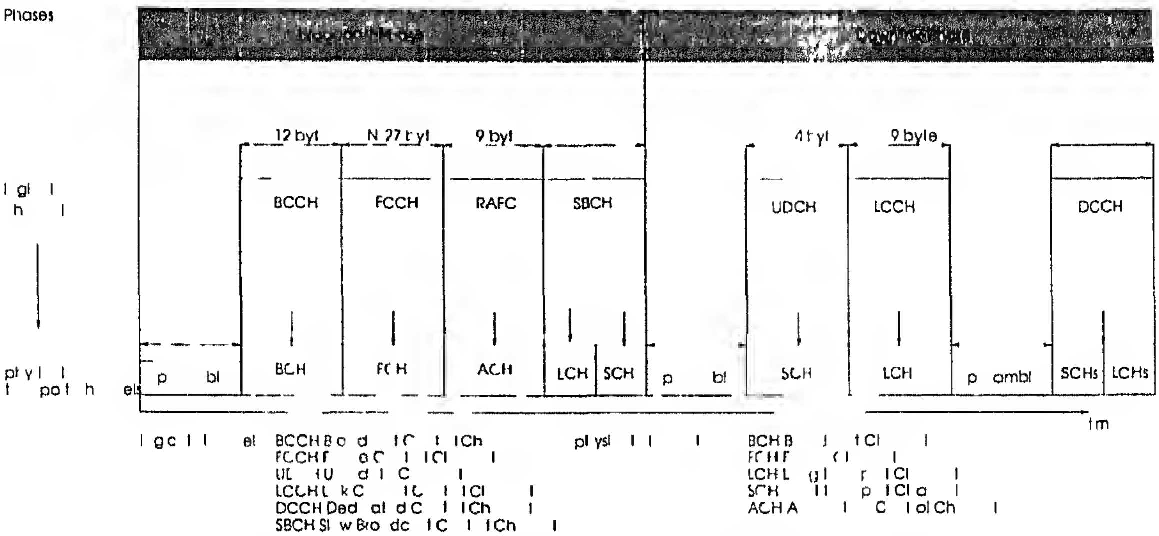


Figure 2.9 Broadcast and Downlink Phases

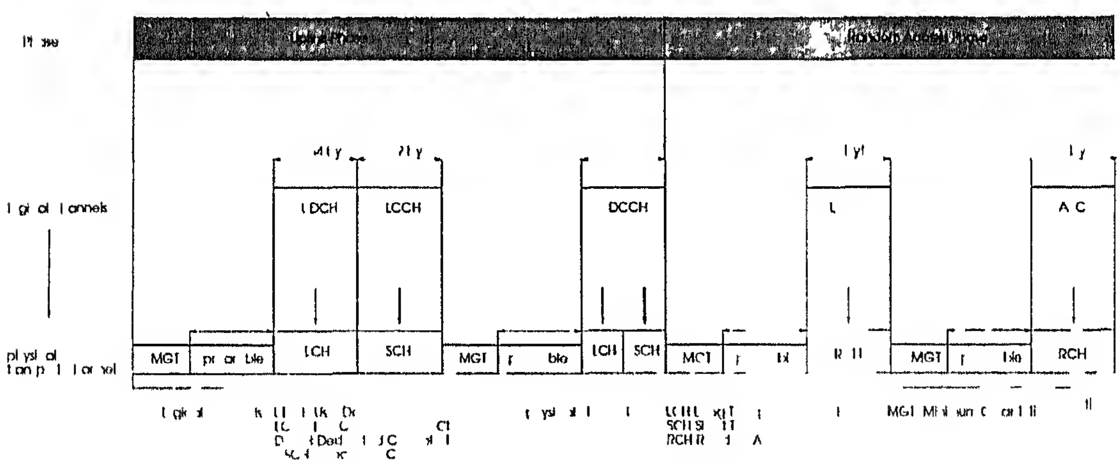


Figure 2.10 Uplink and Random Access Phases

There are two different kinds of PDUs, the Long PDU (LCH PDU) and the Short PDU (SCH PDU). A LCH PDU is 54 bytes long and consists of 48 bytes *payload*, 24 bit CRC24 for error detection, 2 fields for the SAR function of the Convergence Layer and a sequence number for the ARQ protocol (Figure 2.11). A SCH PDU is 9 bytes long and consists of 52 bits for signalling data, 16 bit CRC16 for error detection and an information field of 4 bits to differentiate signalling data from the Radio Link Control (RLC) and the Error Control (EC) data.

In order to save capacity, all LCH PDUs and SCH PDUs belonging to connections of the same MT are combined to so called PDU trains (Figure 2.12). This is done for the up- as

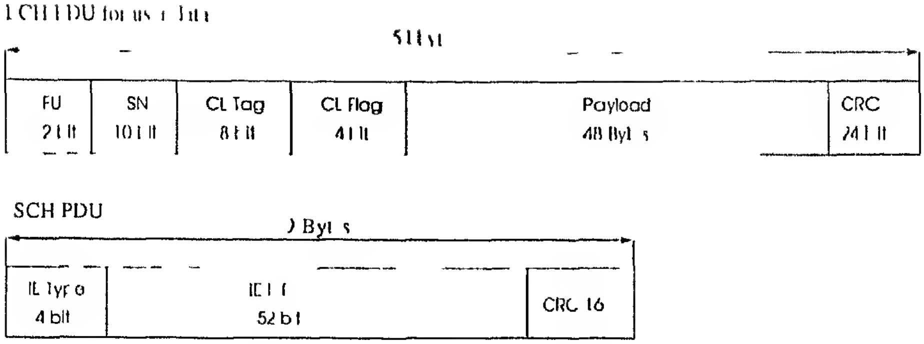


Figure 2.11 LCH PDU and SCH PDU

well as for the downlink. Thus only one preamble per MF is necessary for synchronisation reasons. Further detailed analysis on the MAC layer can be found in [11] and [16].

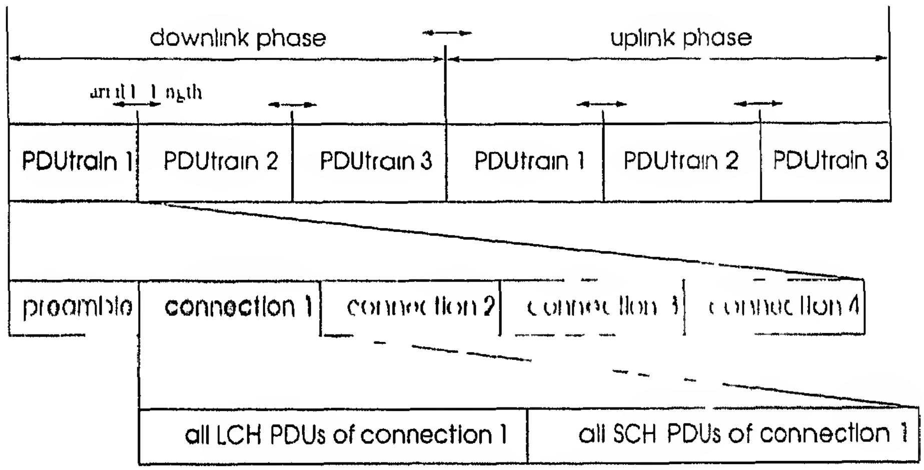


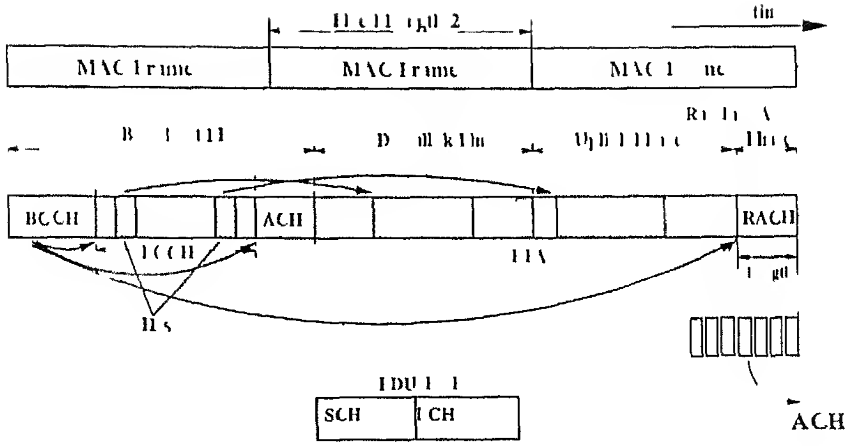
Figure 2.12 Concept of a cell train

Figure 2.13 shows the layout of the MAC Frame. In the FCCH only two IEs (shaded regions) have been shown though FCCH will consist of a train of such IEs contained in FCH PDUs. Each IE points to the DL/UL phases pertaining to one user connection. In the DL/UL phases the shaded region shows LCH/SCH PDU train only for one user connection.

Radio Link Control Protocol

The RLC protocol is situated in the control plane of the DLC layer. It provides three groups of functions for the higher layers. The specifications of the RLC protocol can be found in [15].

- Association Control Functions (ACF)
- Radio Resource Control functions (RRC)
- DLC User Connection Control functions (DCC)



BCCH Broadcast Control CHannel
FCCH Frame Control CHannel
ACH Access Feedback CHannel
TTA Turn Around Time
IE Information Element

SCH Short Channel
LCH Long Channel
RCH Random Access Channel
PDU Protocol Data Unit

Figure 2 13 Transmission phases in a MAC frame

- Association Control Functions

These functions include the protocols for association authentication encryption setup and disassociation The association procedure shall be used by the MTs to get into contact with an AP of a HIPERLAN/2 network

First of all, the MT must scan for the BCCH The BCCH contains the AP ID and the NET ID from the concerned APT The MT then requests for a MAC ID that is valid only in the radio cell of one APT This MAC ID is assigned by the APT and used for addressing the MT during the whole session at this APT

During the Link Capability procedure encryption and authentification procedures are carried out Mutual authentification is supported Within the MT authentification the terminals access to the fixed network is controlled If the authentification fails no access will be granted to the MT The AP authentification procedure help terminals to detect false APs Both authentifications procedures are optional in order to make the system flexible to various fixed network environments and usage More details on authentification and encryption procedures are available in [15]

The disassociation procedure can be initiated either by the MT or by the AP There are basically two types of disassociation explicit and implicit disassociation In the explicit disassociation case both the MT and the AP negotiate about disassociation shortly Implicit disassociation occurs when the MT and the AP lose their radio link before having negotiated about it When the AP notices that a MT has stopped transmitting for a while it will initiate the MT ALIVE procedure In case of no response from the MT the AP will release its resources

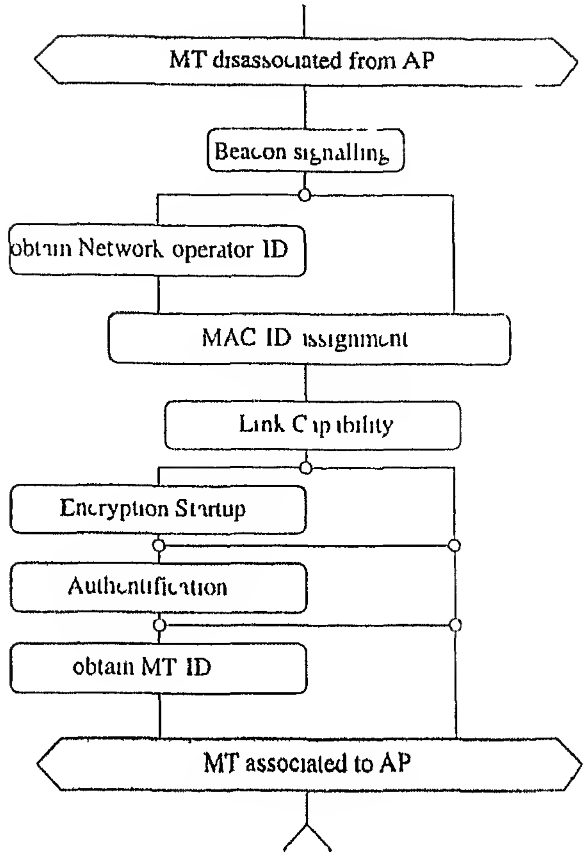


Figure 2.11 Association Procedure

- Radio Resource Control Functions

  The RRC functions provide procedures for radio measurements, handover, dynamic frequency selection, power control and power saving.

  - Measurements

    When associated to an AP the MT constantly measures the quality of the channel. In order to get a complete overview of its radio resource situation the MT has to scan other channels periodically. The measurements are based mainly on the received signal strength.

  - Handover

    Three types of handover might be distinguished: sector handover, radio handover and network handover.

    * During *sector handover* only the antenna sector is changed. The serving APT does not change. The entire handover is controlled by one AP. Higher layers are not involved.

    * A *radio handover* is performed when one MT moves from the coverage area of one APT to another which is served by the same APC. The handover execution is performed within the DLC layer. All relevant information about

on-going connections, security parameters etc. are available in the AP and therefore are not renegotiated. As the MT changes the radio cell, the new APT will assign a new MAC ID. The state of the user connections and their DLCC IDs will stay unchanged.

* A *network handover* is carried out when the MT moves from one APT to another APT controlled by different APCs. As the new APC has no information about this MT, the higher layers are affected. There are two methods by which the APC can get this information. It might get it directly from the MT that will involve a repetition of association procedure. When the network support is available, most of the parameters can be retrieved from the old APC via the backbone. The scheme for the network handover procedure can be seen in Figure 2.15.

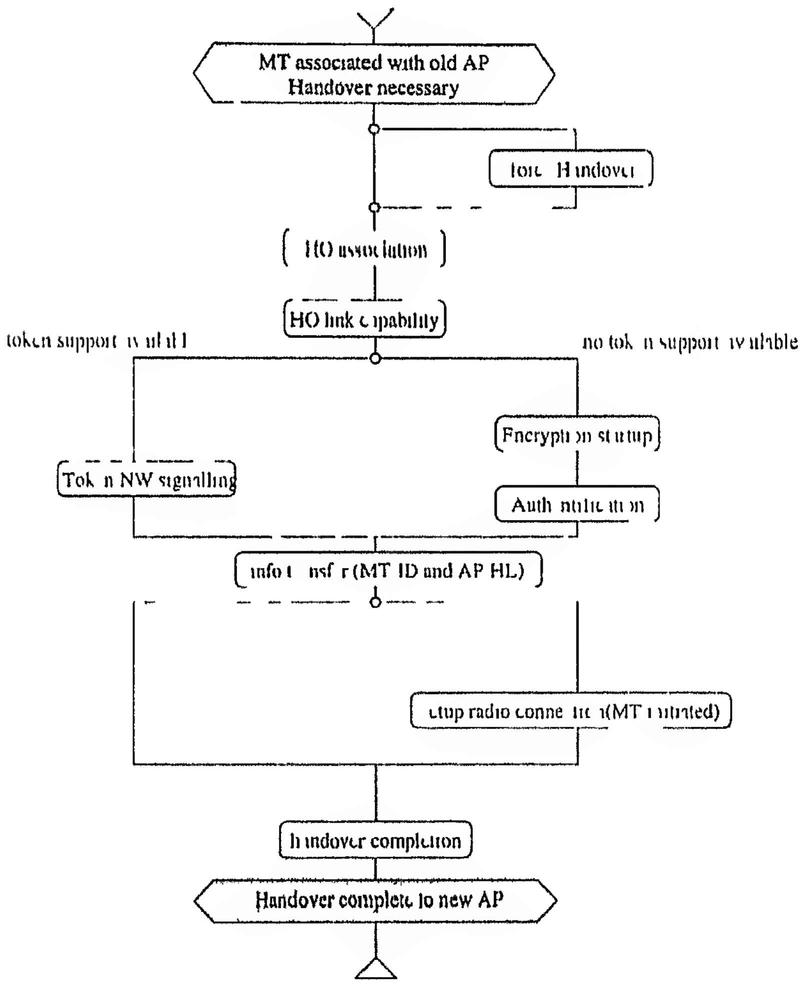


Figure 2.15: Network Handover Procedure

- **Dynamic Frequency Selection (DFS)**

HIPERLAN/2 systems have to share the frequency band with the other systems. This type of sharing requires dynamic adaptation. At start up, the AP has to choose his operating frequency. If interference conditions get worse, the AP must

have the option to switch to another frequency in co-ordination with all MTs associated to it. DFS is mainly based on field strength measurements (carrier field strength and interfering field strength) which are carried out at the AP and the MTs associated to it but the algorithm is controlled by the AP.

- **Power Control**

  According to the distance between an AP and a MT, the quality of the channel and the transmitting power will be adapted during both up and downlink phases. The aim is to minimize potential interference with neighbouring systems.

- **Power Saving**

  This function is responsible for entering or leaving low consumption modes and for controlling the power of the transmitter. This function is MT initiated. The details are available in [15].

- **DLC User Connection Control Functions**

  These control functions are responsible for setting up, maintaining, renegotiating and closing a DLC user connection at the DLC layer. All these procedures may be initiated by the MT or by the AP. A DLCC ID is assigned by the AP. The combination of this DLCC ID and the mobile's MAC ID identifies a connection in a radio cell. Other procedures use these two IDs in order to refer to the connection they want to modify or release. Furthermore, simplex multicast connections are supported. These multicast connections shall not apply ARQ mechanisms.

Error Control Protocol

The EC protocol is responsible for detection and recovery of transmission errors on the radio link. The error recovery is based on Automatic Repeat Request(ARQ) and takes into account, the QoS of each DLC User Connection. The necessity of ARQ arises due to the higher probability of errors in a radio channel compared to wired network. In general, the sender transmits a data packet and buffers it until he receives the corresponding acknowledgement. In case of a negative receipt, the sender retransmits the packet. Detailed analysis of the various methods of ARQ are highlighted in [28].

The HIPERLAN/2 standardisation includes a selective repeat ARQ protocol with partial bitmap acknowledgement. This method is described in the following paragraphs.

The sender assigns every data packet a unique Sequence Number (SN) with the intention to distinguish each data packet from others. When a SN (packet) is missing in the received serial order, the receiver detects the loss of data. The receiver then places a demand for

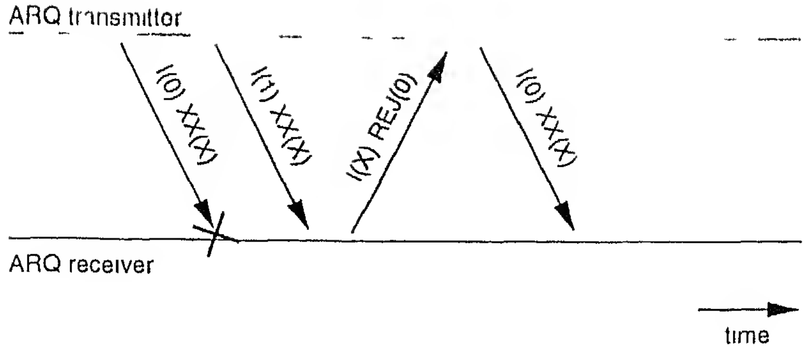


Figure 2 16 ARQ Repetition

these lost data packets by referring to the SN (ref Figure 2 16) A further characteristic of such acknowledgement protocols is the control of data flow by the *Window Mechanism* The size of the window dictates the maximum number of data packets the sender can transmit without receiving an acknowledgement If an ARQ detects a transmission error by missing of a SN a repetition of the missing data packet is initiated There are different methods of ARQ that differ in the handling of errors

The *Selective Reject* ARQ only repeats the missing packet This method of ARQ obtains the best performance The window size is N that means that the sender can transmit N data packets without receiving an acknowledgement Best performance can be reached theoretically by use of an unlimited window size The receiving window also contains N places So the receiver accepts all packets with a sequence number of

$$RN \le SN \le RN + N - 1 \qquad (1)$$

Figure 2 17 represents an exemplary protocol sequence When the packet with expected Receiver Number (RN) arrives it will be transferred to higher layers and the RN will be incremented If a packet with a higher SN is received it will be buffered (here the I Frame with SN=3) The missing I Frames will then be demanded by a SREJ Acknowledge (I Frames SN=1 and SN=2) Until the missing frames are received the data packets will not be transferred to the higher layers in order to keep the sequence of the data packets

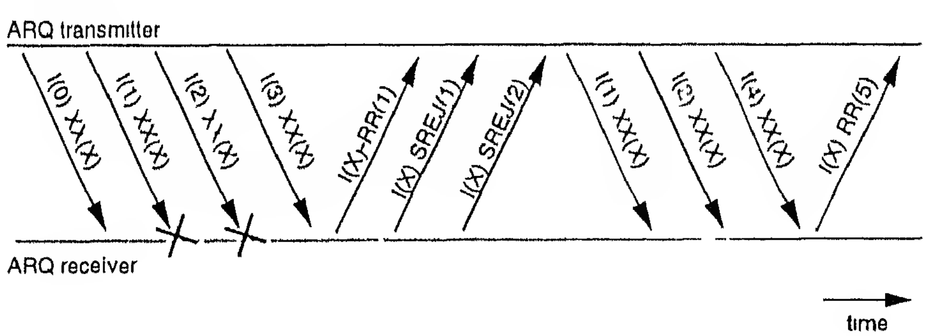


Figure 2 17 Selective Repeat ARQ

Two kind of acknowledgements for ARQ schemes are known namely *Single Acknowledgement* and *Group Acknowledgement* The ETSI favours the *Partial Bitmap Acknowledgement*

This method can be said to belong to the Group Acknowledgements but with slight variation that no negative receipt of a missing SN will be sent. A bitmap of a constant length is appended to the negative acknowledgement of a sequence number. Thus 0 represents an accurately received packet and 1 signifies an error. This way error bursts can be recovered more efficiently as compared to single errors ([12]). Figure 2.18 illustrates the Partial Bitmap Acknowledgement with a concrete example having a constant bitmap of 3.

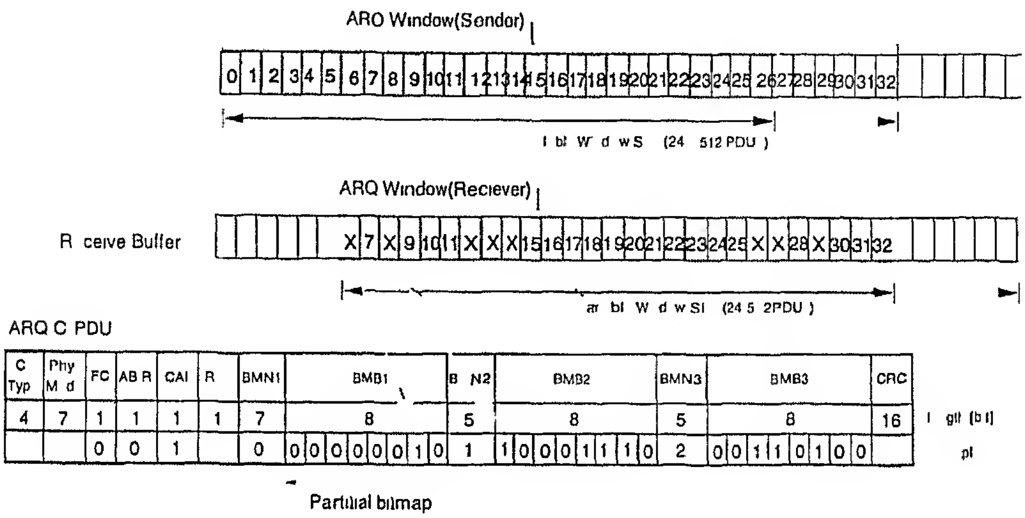


Figure 2.18 Example for a Partial Bitmap Acknowledgement

Here the packets with the sequence numbers 6, 8, 12, 13, 14, 26, 27 and 29 have not been received correctly. The last received packet has the SN 32. In this example, the Partial Bitmap Acknowledgement consists of 3 partial bitmaps each 8 bits long. The first partial bitmap requests the packet with SN 6 selectively. The appended bitmap acknowledges the packets with SN 0-5 and SN 7. The second partial bitmap demands the packets with SN 8 and SN 12-14 and acknowledges packets 9-11 and 15. The third partial bitmap can request the missing packets 26, 27 and 29. The transmission of ARQ information is done by SCH PDUs of the MAC layer.

2.5.3 Convergence Layer

The CL adapts the different core network to the HIPERLAN/2 DLC layer. For each supported core network a special CL is designed. The CL has to provide all functions needed for connection setup and mobility by the core network. Among the supported core networks are IP, UMTS, ATM and IEEE 1394 based systems. There are currently two different types of CLs defined: cell based and packet based (Figure 2.19).

The packet based CL is used to integrate HIPERLAN/2 into an existing packet based

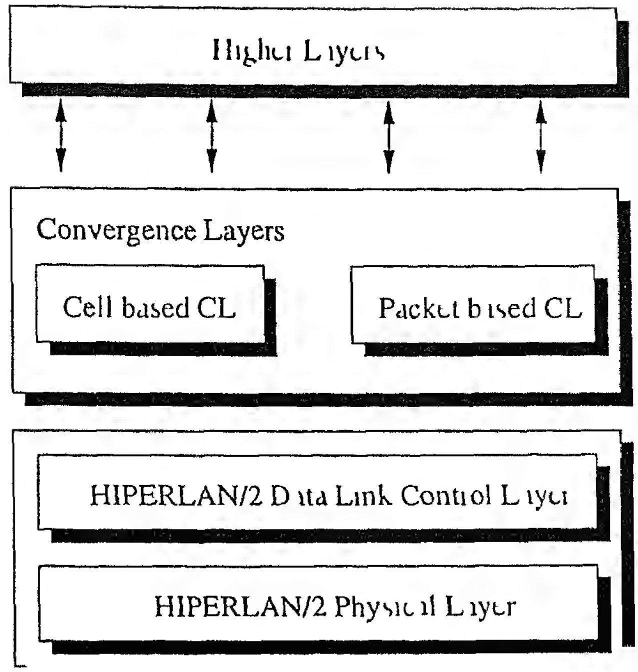


Figure 2.19 Convergence layer to higher layers

network. To support the different technologies used nowadays, the packet based CL includes different profiles, as for example IP, IEEE 802.3 and Point to Point Protocol (PPP). The profiles available at the AP are announced in the BCH phase. The MT chooses one of them during the association. In combination with the *Quality of Service* (QoS) functions of HIPERLAN/2, it will be possible to use the QoS support for IP.

The IP CL has a SAR function to fit the IP packets into the fixed length of a HIPERLAN/2 packet (48 byte payload).

The ATM CL provides the mapping between UNI connection setup procedures and the corresponding HIPERLAN/2 functions. A SAR is not necessary, as the ATM cell and all necessary fields of the ATM header fit into the 54 byte HIPERLAN/2 packet. Nevertheless a compression of the ATM cell header will be necessary.

For further details refer to [21].

Chapter 3

Protocol Specification in SDL

This chapter describes tools and methods for software development used in this thesis. The development of complex telecommunication systems results in the need for specification languages to describe the signalling sequences and the data exchanges both within the systems and between the systems and their environment. One of these languages is the Specification and Description Language(SDL) [23]. SDL is a modern high level programming language. It is object oriented, formal as well as graphical and is intended for the description of complex event driven real time communicating systems.

A SDL specification describes an abstract machine that receives signals from its environment and responds to these signals. In SDL a protocol is represented as a finite state machine, with states and transitions between states.

3.1 Specification and Description Language

The specifications in this thesis have been developed with the SDL Development Tool (SDT) from Telelogic. SDT is a tool to specify and analyse formally specified protocols using the graphical or the phrasal notation of SDL. SDL can describe both the system's interaction with its environment and the system's internal interactions. In its graphical representation SDL allows the hierarchical structuring into several levels of abstraction by means of predefined graphical objects: systems, blocks, sub blocks and processes. Figure 3.1 illustrates an example.

Communication between different objects within the system and between the system and its environment using signal routes and channels are as shown in figure 3.2.

The most abstract level is a system which communicates with its environment by channels. The system is composed of one or more blocks and each block consists of one or more subblocks/processes. A process is the lowest level of abstraction. A process represents a finite state machine and describes a part of the system. A process can be in a state or perform

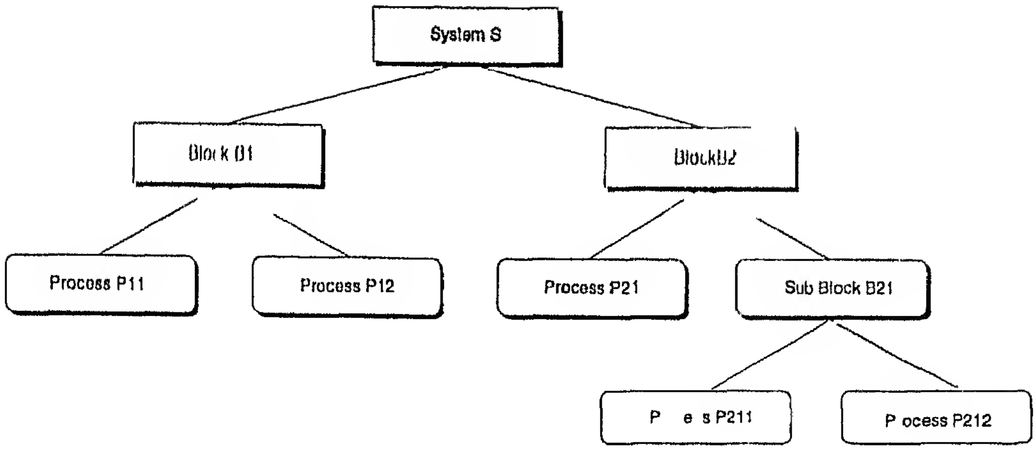


Figure 3.1 SDL hierarchy

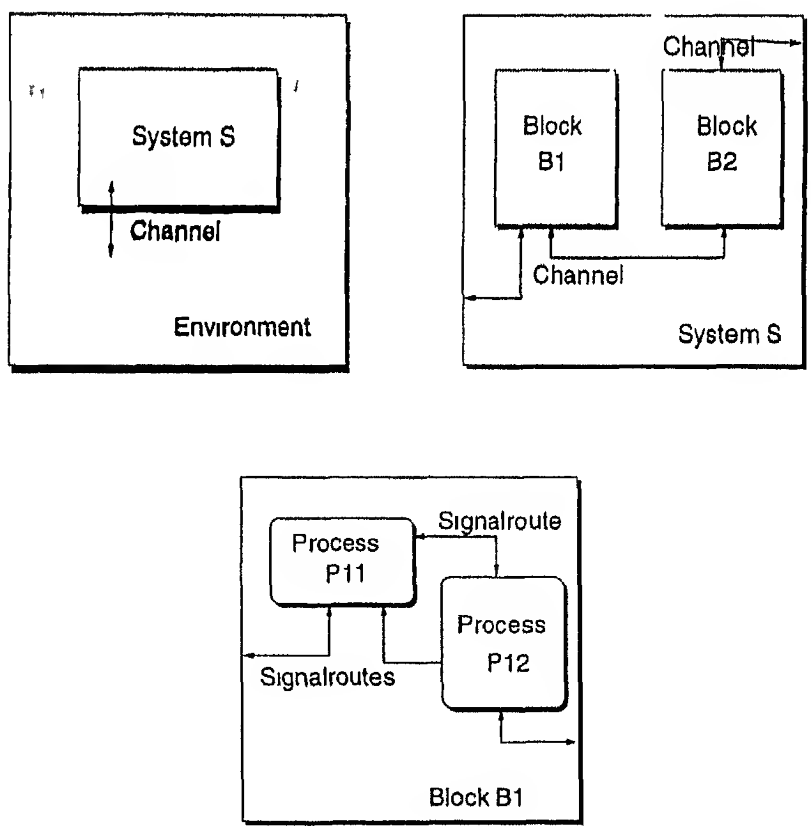


Figure 3.2 SDL structure

a transition between two states The change between two states is triggered by incoming signals When a process receives a signal it is checked if this signal can be consumed in the

current process state. If not, it will be deleted unless the process should store unexpected signals. Each process analyses the signals reaching it and decides upon this information whether to change into another state or remain in a state. If several signals are received at the same time, they are saved in a process signal queue in a random order and served one by one. Passing of time in SDL is defined by timers. A timer is defined by its duration. At the end of this duration the timer triggers the sending of a signal to a process, which indicates that the timer has expired.

3.1.1 Dynamic Process Creation and Process Management

There are two kinds of SDL processes: static processes and dynamically created processes. The prototypes of static and dynamic processes are both defined within the specification of the SDL system. The number of instances of a static process is defined while specifying the system and will be created at the system start. In Figure 3.3 five instances of process P1 will be created at system start.

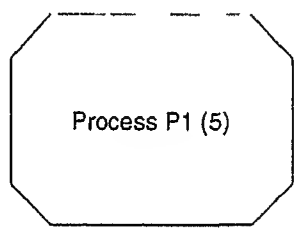


Figure 3.3: Static process creation

Dynamic process creation takes place during runtime of the system. Between changing of states, which is triggered by an incoming signal, a new instance of a defined process type can be created.

The specification of process P2 defines the maximum number of instances at any time (Figure 3.4(a)). The first number defines the amount of statically created instances of process P2 at system start. The creation is always triggered by an incoming signal (Figure 3.4(b)). Within the dynamic process creation parameters can be transferred. This feature allows the handing over of variables from a parent process to the child processes. An SDL process can only be terminated by itself when executing the termination symbol (Figure 3.5).

As a result of this termination, the process, all the data, the contents of its signal queues and its running timers are deleted. Signals on their way to the deleted process are removed

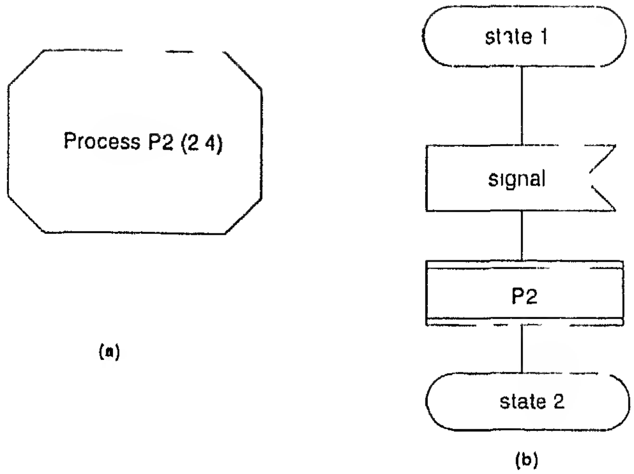


Figure 3.4 Dynamic process creation

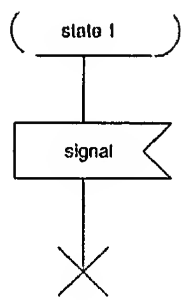


Figure 3.5 SDL termination symbol

from the system

3.1.2 Use of C++ Code via ADTs

SDL offers the access to the C++ classes through Abstract Data Types (ADT). ADTs are used to combine the SDL with implementation languages like C++.

In order to integrate C++ code in a SDL specification, an ADT can be defined as a C++ class or a pointer to a C++ class. In the first case a variable of the defined type will be an instance of the C++ class. In the latter case it will be defined as a pointer to a C++ class. The definitions in Figure 3.7 allow to use the pointer to C++ classes defined in Figure

```
NewType Void
    Literal  NIL
    Default NIL
/ #ADT(T A(S) E(S) D(H) H P)   /
EndNewType

NewType myClassP / #NAME  myClass      /
    Literals
        NIL
        new / #NAME  new myClass    /
    Operators
        new / #NAME  new myClass    /
              Integer
             > myClassP   / #OP(H)   /

        delete
              myClassP
             > Void   / #OP(H)   /

        func
              myClassP  Characte
             > Integer   / #OP(HC)   /

        func
              myClassP
               Void   / #OP(HC)   /
    Default NIL
/ #ADT(T A(S) E(S) D(H) H P)
#TYPE
#include  myClass h
 /
EndNewType
```

Figure 3 6 ADT definition

3 6 inside the SDL specification

```
SDL-PR code                      Possible C++ translation

DCL                              {
    ptr myClassP                     myClass  ptr
    mc  myClass                      myClass mc
    i   Integer                      long i
    v   Void                         // ignored

TASK ptr   - new                     ptr   new myClass
     v       func(ptr)               ptr  func()
     v       delete(ptr)             delete(ptr)
     v     = func(mc)                mc  func()
     i     - func(mc    a )          i = mc  func( a )
                                 }
```

Figure 3 7 ADT usage

The definition as pointer to a C++ class allows the transmission of the pointer as a signal parameter Therefore the same instance of a class can be used in different SDL processes

3.2 SDL Development TOOL (SDT)

The HIPERLAN/2 simulator has been implemented with SDT. SDT is a design tool for the specification of systems based on SDL. SDT is developed by a company called Telelogic and provides many modules for the handling of SDL specifications.

- **Editor**

  The editor is the basis tool that provides all SDL symbols and an editor for text fields. With its help one can create the different hierarchical planes for the system, blocks and processes in a graphical representation. The implementation in a graphical form is also abbreviated as SDL GR.

- **Analyzer**

  The analyzer checks the specification concerning lexical, semantic, syntactic and dynamic correctness.

- **Code Generator**

  The code generator offers the opportunity to transform the graphical description of the system into an executable C or C++ code. The representation of the system in the generated code is called SDL PR (SDL Phrasal).

- **Message Sequence Chart(MSC) Editor**

  With this module one can create diagrams which represent the temporal evolution of signals inside of a SDL specification.

- **Simulator Module**

  The simulator module offers the opportunity to test a specified system and trace the programming steps of process individually. Traces may be displayed interactively with the SDL editor, the MSC editor or in textual form.

[5], [6] and [7] show the details on SDT. The simulation environment in this thesis is implemented in SDL GR. Some of the class libraries have been developed at this chair that are linked to support the event driven simulation (e.g. random generator, evaluation class). Communication Networks Class Library (CNCL) [26] is one such base class. SIMCO class library [1] is another internal library used for controlling simulation parameters e.g. reading default values from a text file. These classes are included in the simulators developed by SDT as ADTs.

Figure 3.8 illustrates the strategy of creating a simulation. The implementation of SDL GR is translated by the SDT analyzer into SDL PR. During this translation a verification of the syntax and the semantic is performed. The SDT code generator translates the SDT PR

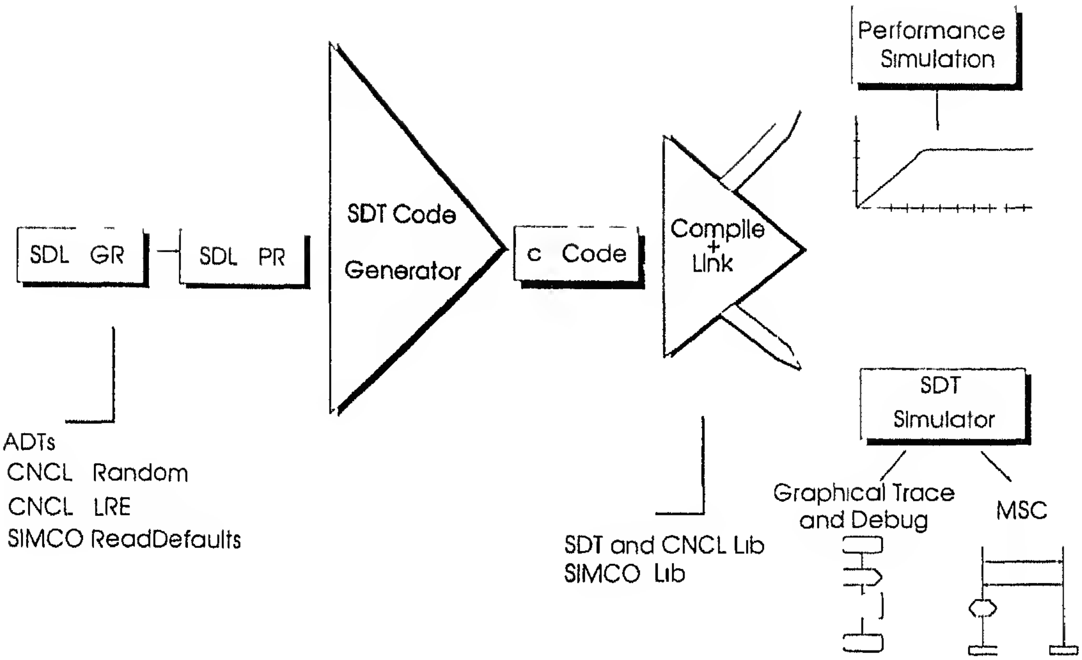


Figure 3.8 Creation of a simulation with SDT

notation into C code. Now SDT student library, CNCL and SIMCO libraries are linked to the generated C code and either a performance simulation or a SDT simulation is produced.

The performance simulation should be used for performance evaluation purposes because of a higher simulation speed, whereas the SDT simulation within the SDT simulator is executed more slowly but offers the following opportunities:

- debugging facility step by step
- creation of Message Sequence Charts (MSCs)

Chapter 4

HIPERLAN/2 Forwarder

A situation can arise when a Mobile Terminal (MT) is unable to communicate with the Access Point(AP). This can result because of a large distance between the AP and the MT or due to obstacles that cause high attenuation in the radio path. With the use of a forwarder it is intended to overcome the difficulties mentioned above on the direct link and thus enhance the communication range of an AP. This chapter provides a brief look into the concepts of forwarding and includes a detailed discussion of a forwarding concept in HIPERLAN/2.

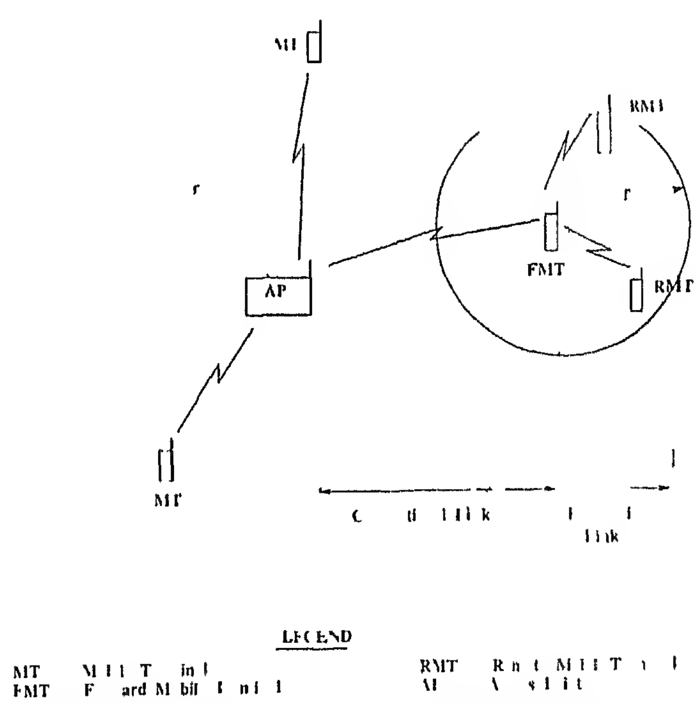


Figure 4.1 Typical outdoor forwarding scenario

4.1 Typical Forwarding Scenarios

Two typical forwarding scenarios are presented below. In Figures 4.1 and 4.2 a Remote Mobile Terminal (RMT) is a MT that cannot communicate with the AP on the *Conventional Link*. The nomenclature *Remote* is used to differentiate it from a normal MT that is connected to the AP on the conventional link and a MT being in the forwarding scenario. One of the MTs associated to the AP on the conventional link and located at the edge of the AP coverage area can perform the function of a forwarder and is thus named Forwarding Mobile Terminal (FMT). Figure 4.1 is generally an outdoor scenario with large distance between an AP and a RMT, where as in an indoor scenario a wall or obstruction is causing high attenuation for a conventional link. An important issue evident from the Figure 4.1 is the communication range or coverage area of the FMT and is discussed later.

4.2 Concepts of Forwarding

Three types of forwarders can be designed based on the concepts given below

- Frequency based concept,
- Time based concept
- Mix of frequency and time based concept

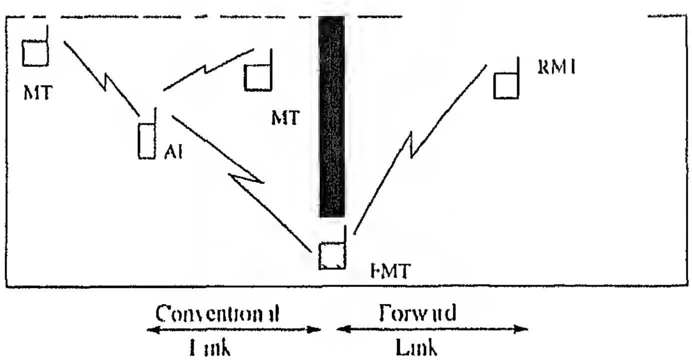


Figure 4.2 Typical indoor forwarding scenario

4.2.1 Frequency Based Concept

The two links, the conventional link and the forward link both operate independently on two different frequencies (Figure 4.3). The concept suffers from a serious drawbacks of having to use two transceivers. Besides increasing the cost, this puts restriction on the size and weight of the MT. The concept also requires a separate *frequency management*, which can

be complex keeping in mind the limited number of frequency channels, smaller cell size and the power output of the terminals.

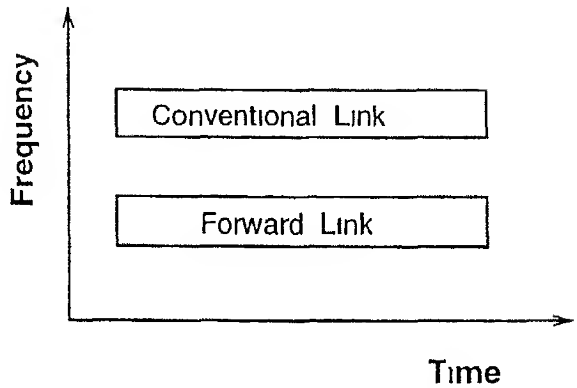


Figure 4.3 Frequency based forwarding

On the other hand the system design can be kept quite simple. The problems of interference can be overcome by proper location of the terminals, controlling power output and using directional antennas.

4.2.2 Time Based Concept

The two links work on time sharing basis on the same frequency (Figure 4.4). This concept solves the problem of an extra transceiver required in the previous frequency based concept. The terminals are thus cost effective and less bulky. The obvious advantages are of course at the expense of reduced throughput as compared to the frequency based concept.

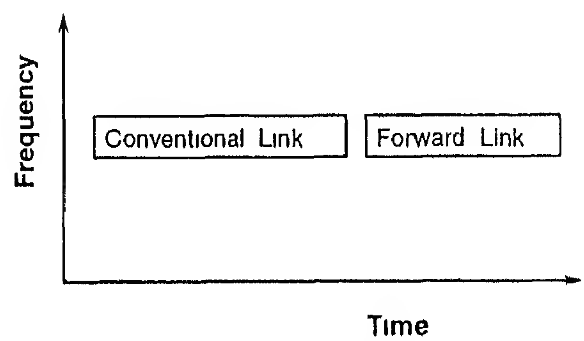


Figure 4.4 Time based forwarding

4.2.3 Frequency and Time Based

Forwarding can also be done using a mix of frequency and time sharing. This concept is a compromise between the two individual concepts mentioned above. Though it has advantages of both of the previous concepts, it will require more complex coordination and the single transceiver should be capable of switching frequency at a higher rate comparable

to the frame length. In Figure 4.5 the conventional link and the forwarding link operate on two different frequencies f_1 and f_2 respectively. The forwarder receives the MF from the AP on f_1 and sends a SF on frequency f_2. It will switch back to f_1 during its own DL/UL phase in MF to communicate with the AP.

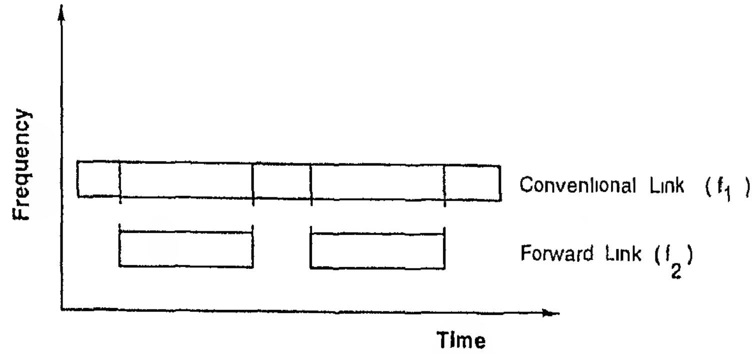


Figure 4.5: Frequency and Time based forwarding

4.2.4 Example Concept: DECT Relay Station

A Relay Station in Digital Enhanced Cordless Telephone (DECT) system [19] called Wireless Relay Station (WRS) follows a similar approach of the frequency and time based concept. The important aspects of DECT WRS is that DECT is a circuit switched network and the WRS is a fixed station. Thus there is a fundamental difference in the proposed concept as HIPERLAN/2 is packet switched network and the relay station is a mobile terminal. A brief introduction to the concept is given below.

In the DECT system the base station is described as Radio Fixed Part (RFP) and the a user terminal is refered to as Portable Part (PP). The WRS contains a Fixed Radio Termination (FT) and a Portable Radio Termination (PT). The key elements of the RFP are built into the FT and the PT contains the key elements of the PP. The FT element acts towards a PP exactly as an ordinary RFP and the FT element acts like a PP towards the RFP. The WRS contains interworking between its FT and its PT. If the relay operates as a pure repeater station then the time slots within the physical layer are interlinked through the relay functions in the physical layer. This transparent service allows data to be transmitted within the same half frame. If the relaying is carried out in the MAC layer, each connection in the relay is assigned its own separate MAC layer entity. This allows it to evaluate independently the quality of the channels and to execute a bearer setup or a handover using dynamic channel selection.

Compared to the RFP, a WRS may introduce capacity restrictions to the services offered. This restriction may increase with the number of cascaded WRS links (hops).

Figure 4.6 shows the frame multiplexing structure for a relay station. Each slot of the WRS can be used as either a receive slot (RX) or a send slot (TX) as decided by the relay

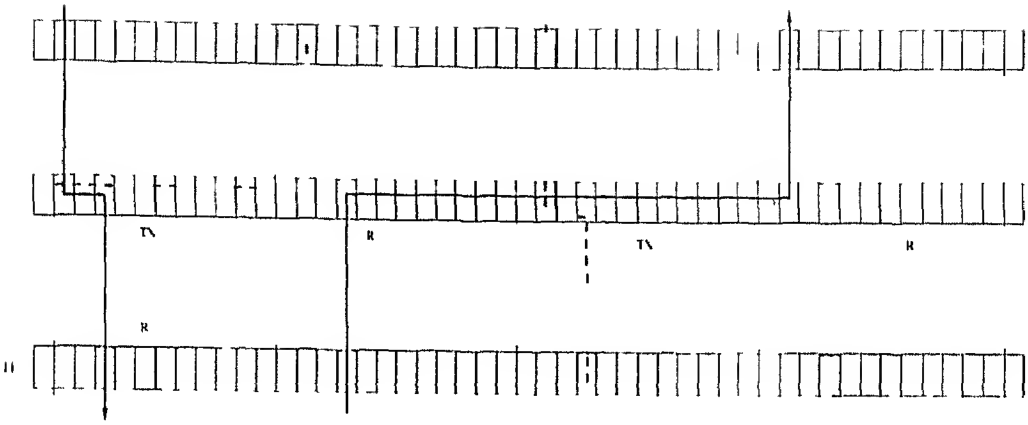


Figure 4 6 Frame multiplexing structure in DECT WRS

During the first half frame (slots 0 to 11) all designated RX slots listen to RFP transmissions and all designated TX slots transmit to PTs In the second half frame all RX slots listen to the PP and all TX slots transmit to the RFP In this example a connection exists between the RFP and the WRS in slot pair 1/13 The corresponding forwarding path between the WRS and the PP is occupying slot pair 3/15

4 2 5 Concept Proposed for HIPERLAN/2

Forwarding in HIPERLAN/2 is still a wide open field It is proposed to first use and test the time based concept The reasons for the choice are listed below

- The sharing of radio ressources on a time sharing basis has an inherent support of QoS parameters as the whole access network is synchronised to a single point in the access system i e the AP which controls and grants the resources used

- HIPERLAN/2 is based on a Time Division Duplex (TDD) concept The entire access network operates on a single frequency though the option of changing to another frequency is available If there is only one single frequency band available in an area due to intersystem interference or regulatory restrictions the proposed time based concept will still be able to operate

- In contrast to known frequency based relay concepts a time based concept does not need extra transceiver or hardware as either the use of different frequencies are not necessary or in a mixed frequency/time based concept the switching points between different frequencies are predefined

- Another important issue relates to the compatibility with the already developed system of HIPERLAN/2 The use of other two options would have made the forwarder incompatible and thus could not have been simulated

- There have been promising results with adhoc networks and also the use of forwarders on frequency based concepts. On the other hand the problem of synchronisation of the resource sharing between two cells is problematic as the forwarder is a member of two cell controlled by two different controllers. Between these cells the support for QoS is problematic and even the implementation is complex as a forwarder consists of two complete MTs including transceivers.

- In the DECT system a relay concept on a mixed frequency/time based concept has already been looked at. But these systems show a fundamental difference as they operate on a circuit switched basis which on one hand eases the organisation aspects but on the other hand does not support best effort services which exploit the capacity temporarily not used by QoS dependent services.

- As already mentioned no extra transceiver hardware is needed. This will keep the individual terminal costs low. The proposed concept aims to support terminals in cases where there is no direct contact to an AP but a relay is reachable. So this concept supports users being in areas where there is no planned support but it is possible to get support instantly with the help of other users. This is possible only if there are many users capable of supporting this concept which is again possible and economical only if the associated equipment is not costly i.e. the concept does not require significant additional costs so that nearly all users are equipped with the additional features.

- The proposed concept must be built with compatibility to the already existing specifications. This feature will allow ready introduction of these systems.

- It is possible to combine the proposed time based concept with concepts on a frequency, coding or even spatial basis. These concepts are expected to further increase the exploitation of the available radio resources.

4.3 Forwarding in HIPERLAN/2

Within this thesis forwarding in HIPERLAN/2 is proposed to be done using the time based concept. The reasons for this choice and the advantages have already been highlighted in section 4.2.5. This section describes in detail the various options available to realise time based forwarding in HIPERLAN/2. From here on, forwarding is meant to be in context to HIPERLAN/2.

4.3.1 MAC Sub Frame

The HIPERLAN/2 Technical Specifications(TSs) specify a MAC Frame(MF) that is shown in Figure 2.13. A Super Frame consists of a train of these MFs. Each MF is divided into four phases of Broadcast(BC), Downlink(DL), Uplink(UL) and the Random Access(RA) phase. Other parameters of the MF have already been described in detail in section 2.5.2.

The *MAC Sub Frame(SF)* in the figure 4.7 is the key element of the proposed forwarding concept. This SF is sent out by the FMT to exchange data between itself and the RMTs associated to it. The UL phase assigned to the FMT is utilized to send this SF. The essential points of the SF are discussed below.

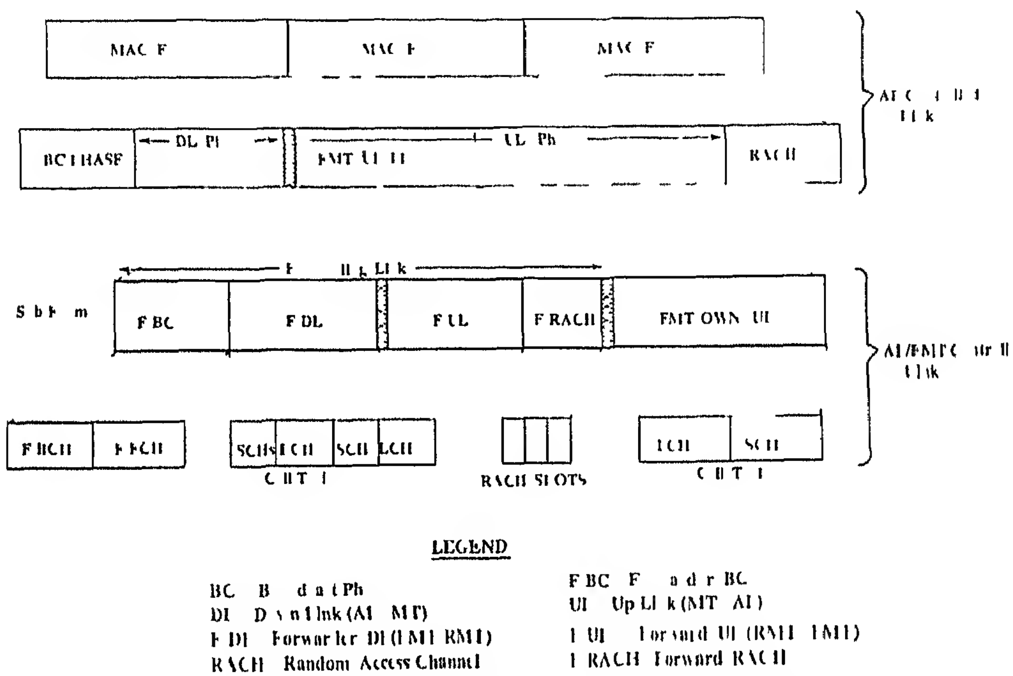


Figure 4.7: Proposed MAC Frame Layout for HIPERLAN/2 Forwarding

- **Similar Structure**

  Since the structure of the SF is similar to that of the MF, a MT can easily receive it when functioning as a RMT. Thus a RMT and a MT can have same design.

- **Control over the SF**

  The control over the SF can be done either by the AP or by the FMT. This includes both scheduling and Resource Grants (RG) and are discussed in subsequent sections.

- **BC Phase**

  The BC Phase includes information regarding the entire cell and is sent in every frame. It has to be sent once again for the RMTs associated to the forwarder. It has been called Forwarding Broadcast Phase (F-BC Phase) in the SF.

- **Phases of the SF**

  The Phases of the SF function are exactly like equivalent phases in the MF. Thus during Forwarder Down Link (F DL) Phase the FMT sends the data packets from FMT to RMT and similarly during Forwarder Uplink (F UL) Phase the FMT receives uplink data from the RMTs.

- **Random Access Channel**

  The Number of *Random Access Slots* in FMT Random Access Channel (F RACH) was reduced to half the number of RACH slots in the MF because of smaller number of RMTs being associated to a FMT than to an AP which leads to a smaller probability of collisions in the F RACH.

- **User Data Flow**

  The flow of user data packets is explained with the help of a diagram (Figure 4.8). In the DL phase the packets meant for the RMT are sent to the FMT in the slots assigned to respective RMTs (RMT is known to the AP). The packets are collected by the FMT and stored in the queues. Subsequently in the F DL phase these packets from the queues are forwarded to the RMT. A similar procedure is followed for UL traffic.

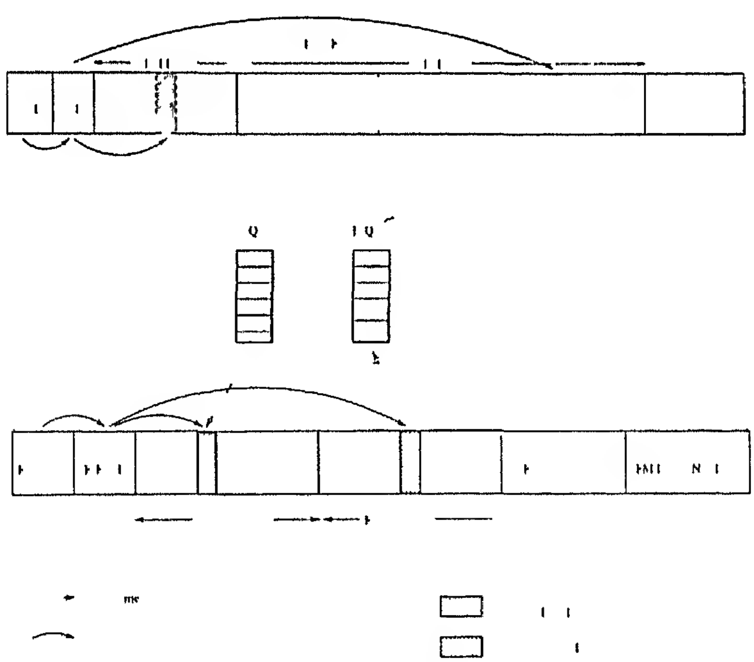


Figure 4.8 User Data Flow

- **Throughput**

  The overall throughput of the system is reduced as the same information is transferred twice. This refers to the control information as well as to the user data packets.

4.3.2 Important Aspects of Forwarding

The previous subsection highlighted some of the important and common features of the SF. There are certain issues like RGs control and management of the SF that dictate the design of a FMT.

- **Compatibility**

  The design of the FMT should be compatible with the HIPERLAN/2 specifications of the AP and the MT.

- **Efficiency**

  The design should offer an acceptable standard in throughput, cell delay and QoS.

- **Sub Network**

  The FMT and its associated RMTs form a Sub Network. It is open how many FMTs should be allowed in the network and how many RMTs should be associated with one FMT.

- **Throughput**

  All RMTs will send Resource Request (RR) to the FMT and the FMT will further add its own RR (if any plus the RR for the SF) and forward the combined RR to the AP. At AP, the RR of FMT will naturally be much more than that of a normal MT. The scheduling strategy adopted for the RGs will thus dictate the throughput at a RMT and a FMT.

- **Control over Forward Link**

  HIPERLAN/2 is a centrally controlled system with entire control done by the AP. Forwarding utilises another link i.e. the forward link (Figure 4.1). The control over the SF includes handling of RRs, RGs and the scheduling. Based on the control over the SF, there can be two possible realisations of the FMT which have been explained in the following:

  - AP Controlled
  - FMT Controlled

4.3.3 AP Controlled SF

In the conventional system, the AP control the resources or assign phases for both DL as well as UL traffic. This is based on the RRs and the available capacity in the MF. This

section highlights the concept where the AP controls the SF on the forward link. The characteristics of the concept are as follows:

- The AP has knowledge of all the active FMTs and also the RMTs associated to each FMT.
- The point mentioned above can be accomplished by reserving separate MAC Identity Numbers(in the TSs) for the FMTs.
- Thus there are three distinct entities in the network i.e. AP, FMT and RMT.
- The SF is also scheduled by the AP in addition to the MF.
- The RRs for both the F-UL and UL Phases are placed with the AP who does the resource management. Since AP is aware of the FMT, it will take care of the large capacity of the FMT.
- FMT is just a forwarder who picks up data from DL/UL slots and forwards them in the F-DL/F-UL slots already assigned by the AP.

Advantages of the Concept

- Since all the RRs (both UL and F-UL) are evaluated by the AP, it can exercise more control over the RCs and thus ensure *fair resource granting* to the FMT and the other MTs. This is due to the fact that the RR of a FMT is much larger than of a normal MT.
- The data packets will suffer less delay since the data can be forwarded in the same MF. This is possible as all the RRs are evaluated the AP and is thus aware of the data that is to be forwarded by the FMT. Therefore the AP can reserve time slots in the MF, for conventional data and for the data that is to be forwarded.
- The FMT will have a simple design. It will not need the scheduler and both the blocks MAC and Forwarder (see Chapter 6) will be simple.

Disadvantages of the Concept

- The concept requires certain additions to the ETSI on HIPERLAN/2 e.g. reservation of MAC identity numbers for the FMTs and new Radio Control Protocols (RCP) for the FMT.
- In this concept the FMT is not compatible with HIPERLAN/2 specifications of AP and MT.

4.3.4 FMT Controlled SF

Similar to the conventional system the AP has full control over the MF here as well but the control over SF is handed over to the FMT. As seen from the RMT, the FMT is acting like an AP and for the AP both RMT as well as FMT are like normal MTs. The following subsection provides an insight into the concept.

- There are only two entities AP and MT in the network. FMT is considered as a MT and thus the AP is not aware of the forwarding link.
- FMT evaluates the RR for the SF in addition to his own RR and sends the combined RR to the AP. The resources for the SF includes F-BCH, F-UL, F-DL and F-RACH phases.
- The UL phase provided to the FMT is *rescheduled* by the FMT into a SF.
- All resource management i.e. compilation of RR, RCs to the RMT, handling of RR with the AP etc. is done by the FMT.
- The FMT has its own scheduler and other routines to handle all the management for the SF.
- A number of queues are maintained at the FMT to store the data packets that are to be forwarded at the appropriate time.
- Resorces for the SF have to be granted by the AP. Thus FMT might not get sufficient resources for the SF, in every MF. This can be overcome by attaching highest priority to the RR of the FMT.

Advantages of the Concept

- The concept can be realised within the available HIPERLAN/2 specifications.
- The FMT is compatible with the specifications of already developed AP and MT.

Disadvantages of the Concept

- As brought out earlier the RGs for the SF is dependent upon the scheduling strategy used at the AP. The present versions of schedulers used by the AP have to be modified to overcome this problem.
- Since the AP treats both the FMT and the RMT as normal MTs, the throughput at the FMT and RMT is reduced and is dependent once again on the scheduling at the AP. The AP is not aware of the forwarding link.

4.4 Parameters for the FMT Controlled HIPERLAN/2 Forwarding

There are some important issues that need to be discussed in this FMT controlled concept of forwarding. The options available are unlimited and each has its own merits.

4.4.1 Throughput and Communication Range of the Forwarder

The concept increases the number of overheads in the MF due to the presence of the SF in case of forwarding scenario. This has implications in reduction of the system throughput. The problem can be overcome by using more spectrally efficient modulation schemes mentioned in the HIPERLAN/2 specifications. The research and simulations presented in the thesis done on the MAC layer of HIPERLAN/2 in the conventional scenario in [11] recommends to use 16QAM with code rate 3/4 for encoding the LCH PDU. Instead we can utilise one of the listed modulation scheme of 64QAM with code rate 3/4 to encode the LCH PDU on the forwarding link. The same can also be considered for the other PDUs. The consequences of this is the reduction in the communication range of the forwarder if the same probability of error is to be maintained on the channel.

4.4.2 Length of the SF

The ETSI Specifications of HIPERLAN/2 specify that the length of the MF is fixed at 2 ms. The length of the SF is variable upto 2 ms and depends upon the resources granted by the AP. The BCCH specifies the starting bit of the RACH and the number of RACH slots. The MT synchronise or waits for the next frame at the end of RACH. Similarly in the SF the F-BCCH specifies the starting bit and the number of F-RACH slots. The RMT waits for the next frame at the end of F-RACH slots.

4.4.3 Data Queues at Forwarder

The cells arriving at the FMT from either direction have to be stored temporarily before they are forwarded to the appropriate destination. The storage is done in the queues maintained at the forwarder. An important point here is not to allow the queues to overflow. This can happen in case the incoming data rate is higher than the outgoing rate. The higher or at least equal outgoing data rate can be maintained by sufficient allocation of capacity for the SF. This can be achieved at the scheduler by giving priority in the allocation of capacity. Another point is to have sufficient memory in the hardware. The average length of the queue will depend upon the traffic characteristics. The memory space can be worked out for the maximum throughput.

4.4.4 Sufficient Capacity for SF

The forwarder will put restrictions on the services to the RMTs. This is due to the availability of the capacity. At the AP resources are granted or scheduled based on the RRs of the MTs and the available capacity. It is obvious that the RR from the FMT will be very high compared to that of a MT. Problems occur only at temporary system overloads and are highlighted with the help of a Figure 4.9.

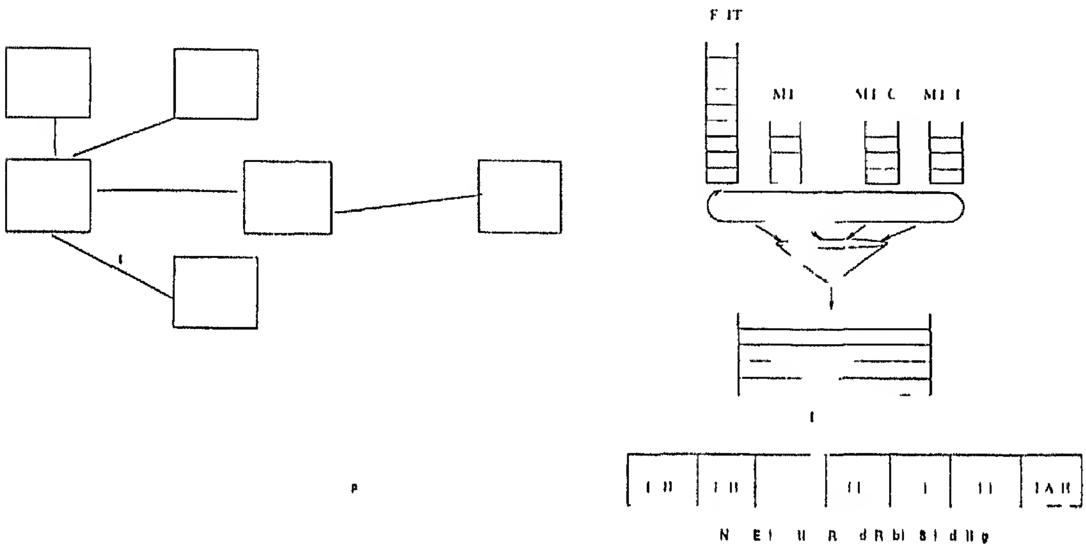


Figure 4.9: Existing scheduling

There are three MTs, one RMT and a FMT associated to the AP. Each one has a user connection (ABCD). In figure 4.9 the figure on the right shows the scheduling startegy at the AP with respect to the connection set up figure on the left. The RR from each of the connections of MT/FMT/RMT is shown in the bins at the top of the figure. The first bin is of FMT and has 9 packets (A1 to A9) in the queue and this includes RR for the SF as well. The result of the scheduling(Non Exhaustive Round Robin) is shown in the MF constructed at the bottom of the figure on the right. We see that like the all other MTs, capacity for only one packet is allotted to the FMT, inspite of the FMT having three times larger request.

The solution adopted to this problem is shown in Figure 4.10. The FMT can demand more user connections, one each for a RMT and the F-BC phase. In the example shown in the figure it now has three connections, one for the F-BC phase, one for the SF and one for itself. Since the RR and thereafter scheduling is connection based, the RR at the scheduler is divided into three separate requests as shown in the bins A1 to A3. The result of the same scheduling strategy is shown in the MF at the bottom.

This solution leads higher number of connections to be handled. Therefore there will be less connections possible for other RMTs. A better solution is to have an improved scheduler

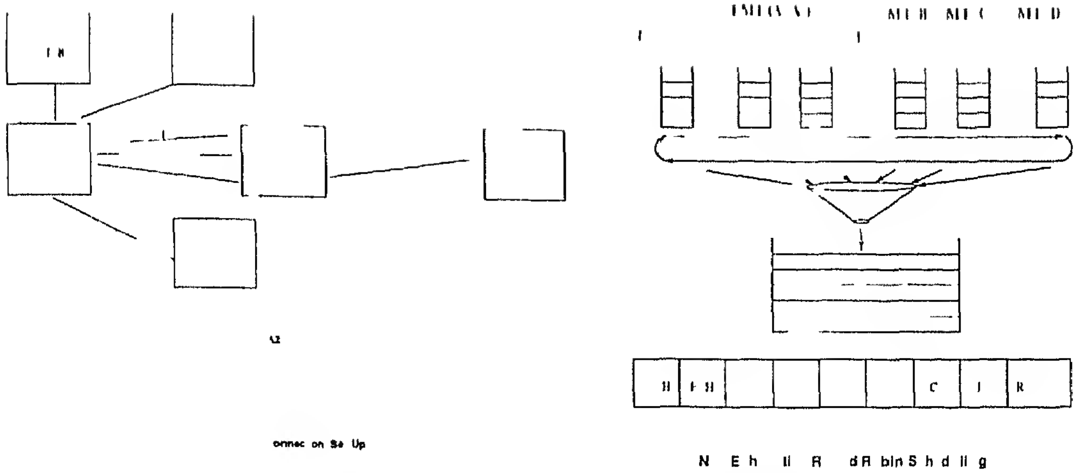


Figure 4 10 Solution to the scheduling

that keeps in mind the length of the requests and does fair capacity allocation scheduling in HIPERLAN/2 but this will lead to the AP controlled concept warranting a change in the HIPERLAN/2 specifications

Chapter 5

Theoretical Analysis

Having understood the HIPERLAN/2 System and the forwarding concept employed for HIPERLAN/2 (in this thesis), this chapter will focus on the related theoretical analysis. This analysis will form the basis for the simulations and the practical analysis discussed in the next chapter.

The following aspects have been analysed and are presented in the subsequent sections:

- System Throughput
- Overheads due to the forwarder
- Probability of PDU Loss

5.1 System Throughput

The structure of the HIPERLAN/2 MAC protocol is highly flexible. The length of FCH and RCH varies and is dependent upon the number of MTs (n_{MT}), the user connections per MT (n_{conn}), the number of FMTs (n_{FMT}) and the number of RMTs associated with each FMT (n_{RMT}). The data rate is further affected by the modulation scheme and the code rate adopted to transmit the PDUs. The analysis is aimed at calculating maximum throughput with respect to the variables mentioned above.

5.1.1 Conventional Link Parameters

BCH PDU The BCH is 15 bytes long and is always encoded using BPSK with code rate 1/2. It is sent in every frame with a preamble of 4 OFDM symbols. Each OFDM symbol has 3 bytes when encoded with BPSK 1/2. The length of the BCH PDU (L_{BCH}) is therefore given by

$$
\begin{aligned}
L_{BCH} &= \frac{15}{3} + Preamble_{BCH} \\
&= 5 + 1 = 9 \qquad OFDM Symbols
\end{aligned}
\tag{1}
$$

FCH PDU The FCH has a variable length and is dependent upon n_{MT} and n_{conn}. Each FCH PDU is 27 bytes long or a multiple of 27 bytes. A FCH PDU consists of three 8 byte Information Elements (IE) and 3 byte CRC-24. Each connection requires two 8 byte IEs for the DL and the UL traffic as the user connections are bidirectional. FCH can be encoded with any of the modulation schemes and thus the length of FCH PDU (L_{FCH}) is dependent upon the modulation as given below

$$
L_{FCH} = \left\lceil \left\lceil \frac{2 * n_{conn} * 8}{24} \right\rceil * \frac{27}{BpS_{FCH}} \right\rceil \tag{2}
$$

The BpS_{FCH} represents the number of bytes per OFDM Symbol depending upon the modulation and the code rate used for the FCH.

RCH PDU The length of RCH PDU depends upon the number of RCH Slots ($Slots_{RCH}$) in one MF. Each RCH slot is 9 byte long and is always encoded using BPSK 1/2. A preamble of 4 OFDM symbols is attached to each slot. The total length is therefore given by

$$
\begin{aligned}
L_{RCH} &= Slots_{RCH} * (3 + Preamble_{UL}) \\
&= Slots_{RCH} * 7
\end{aligned}
\tag{3}
$$

ACH PDU The ACH PDU is 9 bytes long and is again always encoded using BPSK 1/2. The length of ACH PDU is then

$$
L_{ACH} = \frac{9}{3} = 3 \tag{4}
$$

Downlink and Uplink Phase Each cell train in both uplink and downlink phases are preceded by a preamble. One cell train carries data from one MT and thus the total preamble length is dependent upon the number of MTs. The downlink preamble is 2 OFDM symbols and the uplink preamble is 3 OFDM symbols long. In the uplink phase every user connection is provided with a SCH PDU for the next resource request. For the downlink phase

$$L_{DL} = n_{MT} * Preamble_{DL} \tag{5}$$

For the uplink phase

$$L_{UL} = n_{MT}\left[Preamble + n_{conn} * \frac{9}{BpS_{SCH}}\right] \tag{6}$$

The BpS_{SCH} represents the number of bytes per OFDM Symbol depending upon the modulation scheme and the coderate used for the SCH PDU

5.1.2 Forward Link Parameters

The parameters mentioned in the previous section apply to the MAC Sub Frame (SF) on the forward link as well. The only changes are in the modulation and the coderate used for the FCH, the SCH and the LCH PDUs

F BCH PDU The BCH PDU on the forwarding link (L_{F-BCH}) is same as the BCH PDU on the conventional link

$$L_{F-BCH} = L_{BCH} \tag{7}$$

F FCH PDU The only difference between the FCH PDU on the forwarding link (L_{F-FCH}) and the one on the conventional link is the modulation and the coderate used. Therefore

$$L_{F-FCH} = \left\lceil\left\lceil\frac{2 * n_{conn} * 8}{24}\right\rceil * \frac{27}{BpS_{F-FCH}}\right\rceil \tag{8}$$

The BpS_{F-FCH} represents the number of bytes per OFDM Symbol depending upon the modulation and the coderate used for the FCH PDU on the forwarding link

F RCH The number of RCH slots on the forward link are reduced due to the fact that the number of RMTs is less. Otherwise it is same as the RCH PDU on the conventional link

$$L_{F-RCH} = L_{RCH} \tag{9}$$

F-ACH PDU, DownLink and Uplink Phase Preamble This parameter is again same to the one on the conventional link

$$L_{F-ACH} = L_{ACH} \tag{10}$$

$$L_{F-DL} = L_{DL} \tag{11}$$

$$L_{F-UL} = n_{RMT} \left[Preamble + n_{conn} * \frac{9}{BpS_{F-SCH}} \right] \tag{12}$$

5.1.3 Analysis Parameters

The length of each MF is 2 ms and the length of each OFDM symbol is 4 μ. Thus the total number of OFDM symbols in one MF is 500. Using equations 1 - 12 the length of the total number LCH PDUs can be calculated for both the conventional as well as the forwarding scenarios.

For the conventional scenario

$$\begin{aligned} L_{LCH} &= 500 - L_{BCH} - L_{FCH} - L_{ACH} - L_{DL} - L_{UL} - L_{RCH} \\ &\quad OFDMSymbols \end{aligned} \tag{13}$$

For the forwarding scenario

$$\begin{aligned} L_{LCH} &= 500 - (L_{BCH} - L_{FCH} - L_{ACH} - L_{DL} - L_{UL} - L_{RCH}) \\ &\quad -((L_{F-BCH} - L_{F-FCH} - L_{F-ACH} - L_{F-DL} - L_{F-UL} - L_{F-RCH}) * n_{RMT}) \\ &\quad OFDMSymbols \end{aligned} \tag{14}$$

Table 5.1 Variable parameters for system throughput on conventional link

The LCH PDU is 54 bytes long and depending upon the modulation and the coderate used, the number of LCH PDUs in one MF can be calculated as below

$$NB\_LCH = \left\lfloor \frac{L_{LCH}}{\left\lceil \frac{1}{BpS_{LCH}} \right\rceil} \right\rfloor \tag{15}$$

Each LCH PDU has a payload of 48 bytes and the duration of MF is 2 ms, thus

$$Throughput = \frac{NB\_LCH * 48 * 8}{t_{Frameduration}} \frac{[Mbit]}{[s]} \tag{16}$$

Table 5.1 Variable parameters for system throughput on conventional link

Scenario	Phy Mode FCH & SCH	Phy Mode LCH
$n_{MT} = 1$ $n_{com} = 1$	BPSK1/2 $BpS_{FCH} = BpS_{SCH} = 3$	BPSK1/2 $BpS_{LCH} = 3$
$n_{MT} = 1$ $n_{com} = 1$	BPSK1/2 $BpS_{FCH} = BpS_{SCH} = 3$	16 QAM3/4 $BpS_{LCH} = 18$
$n_{MT} = 1$ $n_{com} = 1$	16 QAM3/4 $BpS_{FCH} = BpS_{SCH} = 18$	16 QAM3/4 $BpS_{LCH} = 18$

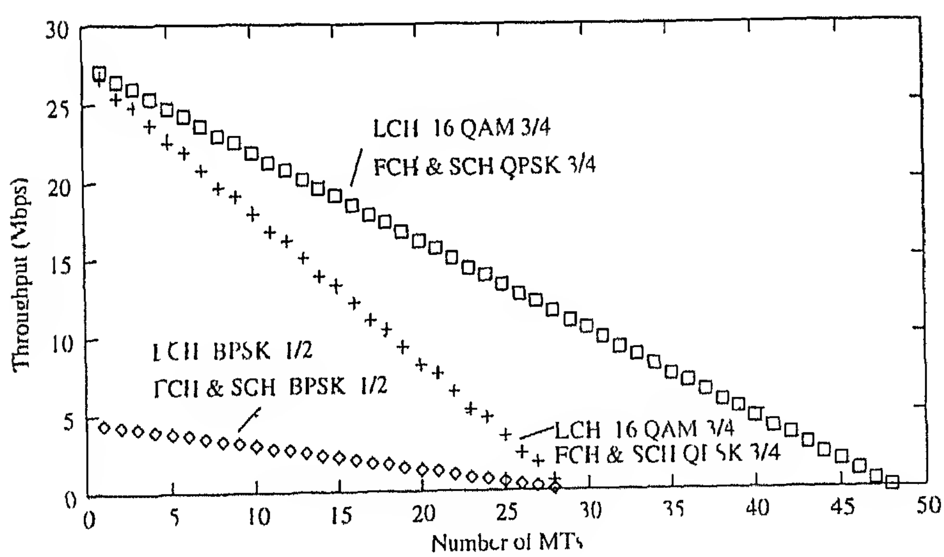


Figure 5.1 System throughput on the conventional link

5.1.4 Analysis Results

The system throughput was calculated for both the conventional and the forwarding scenarios. The values of the variable parameters have been shown in a tabular form. Though the conventional scenario has already been analysed earlier [11], it is reproduced here for comparison.

Table 5 2 Variable parameters for system throughput on the forward link

Scenario	Phy Mode I FCH & F SCH	Phy Mode F-LCH
$n_{RMT} = 1$ $n_{conn} = 1$	BPSK1/2 $BpS_{F-FCH} = BpS_{F-SCH} = 3$	BPSK1/2 $BpS_{F-LCH} = 3$
$n_{RMT} = 1$ $n_{conn} = 1$	BPSK1/2 $BpS_{F-FCH} = BpS_{F-SCH} = 3$	16 QAM3/4 $BpS_{F-LCH} = 18$
$n_{RMT} = 1$ $n_{conn} = 1$	16 QAM3/4 $BpS_{F-FCH} = BpS_{F-SCH} = 18$	16 QAM3/4 $BpS_{F-LCH} = 18$
$n_{RMT} = 1$ $n_{conn} = 1$	BPSK1/2 $BpS_{F-FCH} = BpS_{F-SCH} = 3$	BPSK1/2 $BpS_{F-LCH} = 3$
$n_{RMT} = 1$ $n_{conn} = 1$	BPSK1/2 $BpS_{F-FCH} = BpS_{F-SCH} = 3$	16 QAM3/4 $BpS_{F-LCH} = 18$
$n_{RMT} = 1$ $n_{conn} = 1$	16 QAM3/4 $BpS_{F-FCH} = BpS_{F-SCH} = 18$	16 QAM3/4 $BpS_{F-LCH} = 18$

Analysis Results Conventional Scenario

The variable parameters for this scenario are listed in Table 5 1 The first column gives the number of MTs and the number of user connections The 2nd and the 3rd columns specify the modulation scheme and the coderate used for the FCH/SCH PDUs and the LCH PDUs respectively Three different combinations have been shown the worst case is given in the first row then the best case and finally the recommended case The recommended case corresponds to using BPSK 1/2 for the FCH and the SCH PDU and 16QAM 3/4 for the LCH PDU

Analysis Results Forwarding Scenario

The analysis has been done with respect to the most recommended combination of using BPSK 1/2 to encode FCH and SCH PDUs and using 16QAM 3/4 for LCH PDUs on the conventional link. The combinations of variable parameters on the forward link have been listed in the Table 5.2. Three different combinations, the best, the worst and the recommended cases of the modulation schemes and the code rate have been analysed.

- **Case I**

  Figure 5.3 shows a graph plotted for the maximum system throughput on the y axis and the number of FMTs on x axis. Each FMT has further one RMT with one connection associated to it. Maximum possible throughput is 29 Mbps with only one FMT and one RMT with one user connection and the minimum is given by 7 FMTs and 7 RMTs.

- **Case II**

  The variable parameter on the x axis is now the number of user connections. The system set up has one FMT and further one RMT associated to the AP. The user connections are varied between the AP and the RMT. Figure 5.2 shows the plot for this scenario.

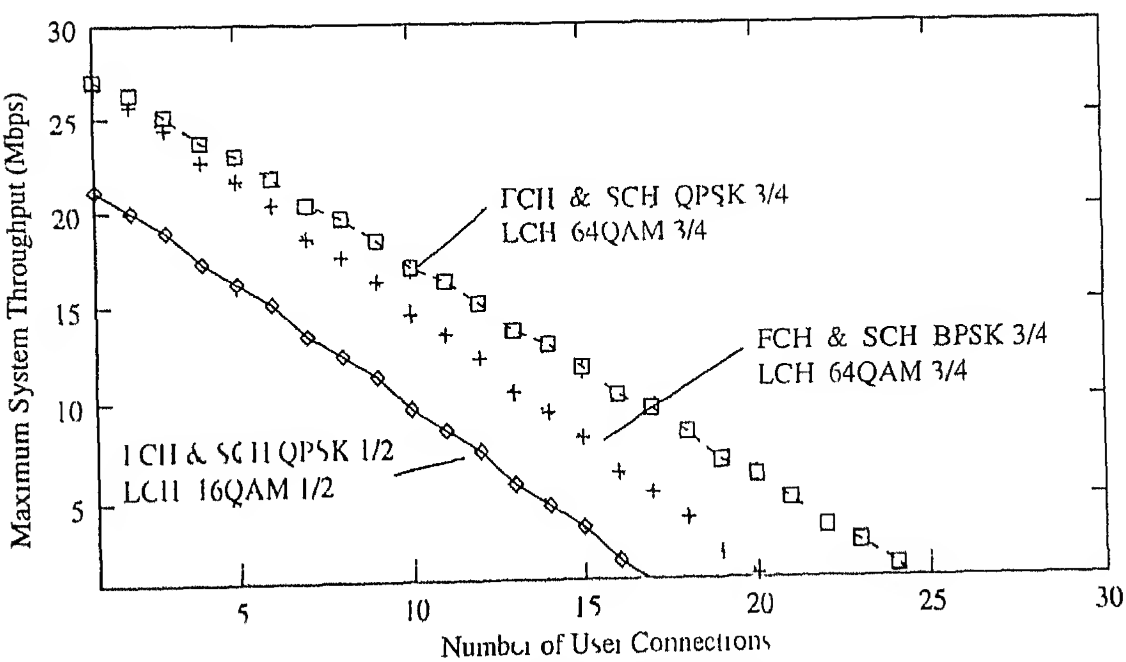


Figure 5.2 Maximum system throughput (Case II)

- **Case III**

  This analysis is done for the variable number of RMTs plotted on the x axis in Figure 5.4. One FMT is associated to the AP and the number of RMTs is varied. Three plots

have been shown for one, two and three user connections. The modulation scheme used is BPSK 3/4 for FCH and SCH PDU and 64 QAM 3/4 for LCH PDU on the forward link. The conventional link has the most recommended modulation schemes mentioned above.

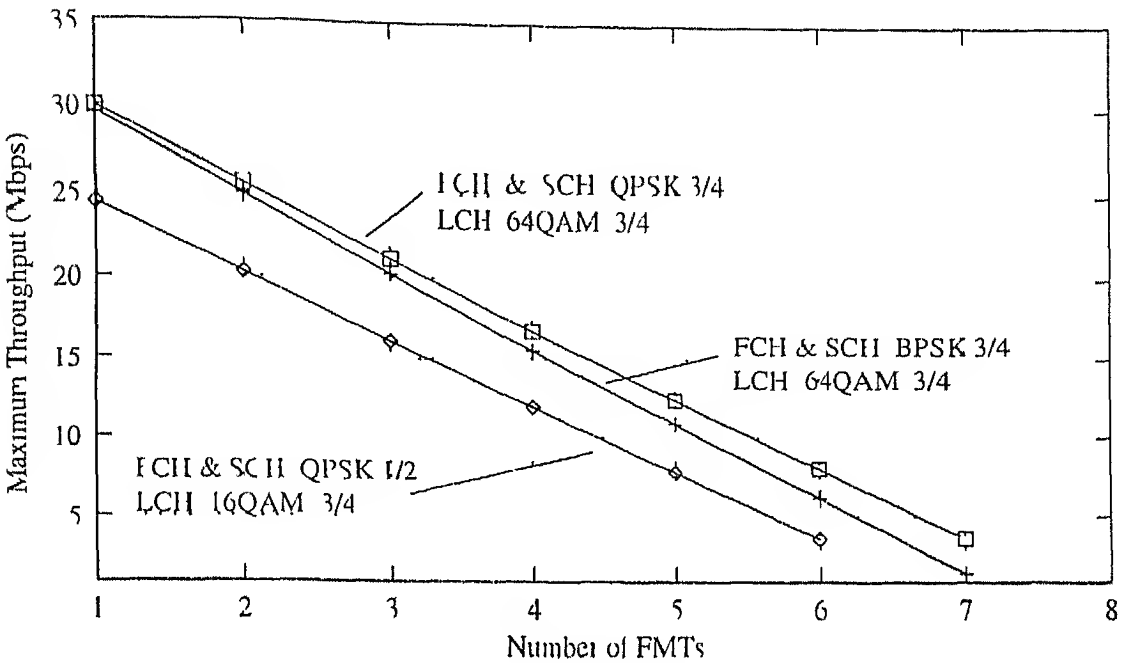


Figure 5.3 Maximum system throughput (Case I)

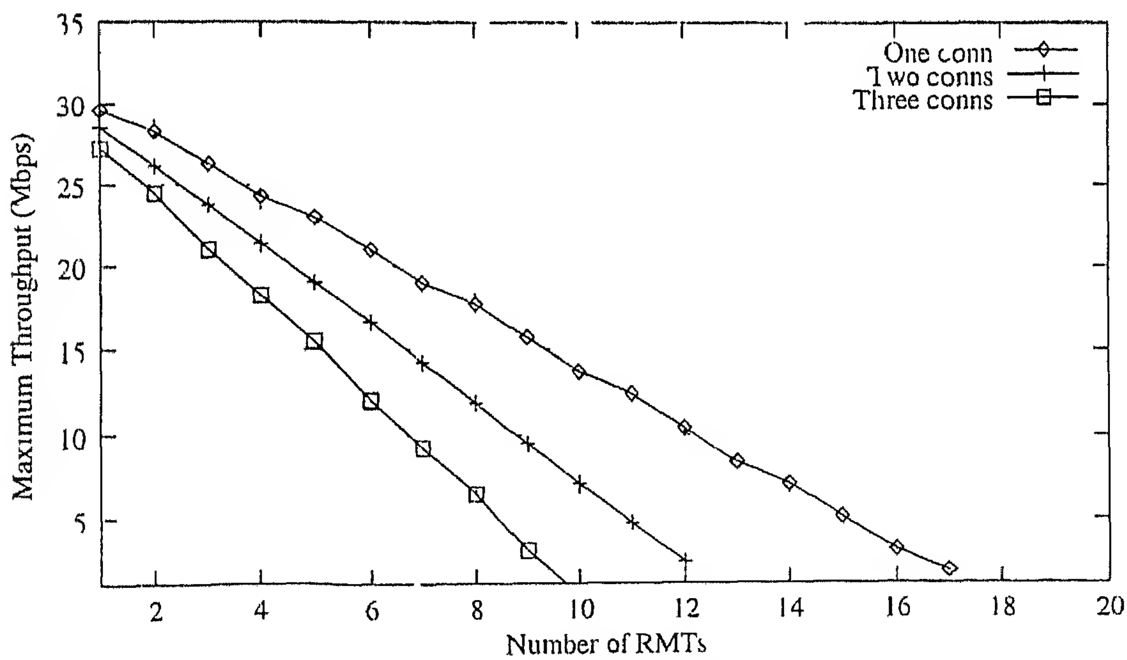


Figure 5.4 Maximum system throughput (Case III)

As can be seen from the graphs, the worst case is given by using BPSK 1/2 for FCH/SCH PDUs and 16 QAM 3/4 for LCH PDUs. The recommended case is to use BPSK 3/4 for the FCH/SCH PDUs and 64QAM 3/4 for the LCH PDUs.

5.2 Analysis of Organisational Information

The parameters mentioned in the section 5.1 also apply to the analysis of organisational information needed. The result is again dependent upon n_{MT}, n_{FMT} and n_{RMT}. This analysis has been done in two parts, the first one giving a picture of organisational information in the conventional scenario and the second one representing the forward link.

Organisational Information on the Conventional Link The equations 1 through 6 have been used in the analysis. The organisational information needed on the conventional link (OH_{CL}) can be calculated as below.

$$OH_{CL} = \frac{\frac{I_{BCH} + I_{FCH} + I_{RCH} + I_{ACH} + I_{UL} + I_{DL}}{500}}{OFDMSymbols} \tag{17}$$

Organisational Information on the Forwarding Link The equations 7 through 12 have been used to analyse the organisational information needed on the forwarding link (OH_{FL}). Though the parameters are the same as in previous case, but the modulation and code rate used are different.

$$OH_{CL} = \frac{\frac{OH_{CL} + L_{BCH} + I_{FCH} + I_{RCH} + I_{ACH} + I_{UL} + I_{DL}}{500}}{OFDMSymbols} \tag{18}$$

Graphical Results The analysis has been done with the parameters listed in the Table 5.3. The organisational information needed on the conventional links have been plotted and shown in Figure 5.5. The graphs have been plotted for percentage of organisational information on y axis and the number of MTs/FMTs on the x axis. The plot is for the worst case scenario assuming that each MT/FMT will be served in each of the MF with at least one LCH PDU to be transmitted in the both up and down link phases. Though in real scenarios all MTs might not be served in each MF and this is dependent upon the scheduling strategy used to resolve overloaded conditions. The limits indicate the number of MTs that can be served in one MF corresponding to the percentage overhead. For instance on the conventional link in one MF 21 MTs with one connection each and being served one LCH PDU in either direction will have 72 % of the overall load used to organise the system.

In case of organisational information needed on the forward link (Figure 5.6), the x axis shows the number of FMTs associated to the AP and each FMT has one RMT

Thus 6 FMTs imply 12 MTs associated to the AP. The FMT has no traffic of its own and is only functioning as a forwarder.

Table 5.3 Parameters for organisational information analysis

Parameter	Value
Conventional Link Parameters	
Number of RACH slots	Four
Modulation BCH PDU	BPSK 1/2 (5 OFDM Symbols)
Modulation ACH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation LCH PDU	16 QAM 3/4 (3 OFDM Symbols)
Modulation FCH PDU	BPSK 1/2 (9 OFDM Symbols)
Modulation SCH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation RCH PDU	BPSK 1/2 (3 OFDM Symbols)
PHY Overhead (Preamble) in Uplink	4 OFDM Symbols
PHY Overhead (Preamble) in Downlink	2 OFDM Symbols
Forward Link Parameters	
Number of RACH slots	One
Modulation BCH PDU	BPSK 1/2 (5 OFDM Symbols)
Modulation ACH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation LCH PDU	64 QAM 3/4 (2 OFDM Symbols)
Modulation FCH PDU	BPSK 3/4 (6 OFDM Symbols)
Modulation SCH PDU	BPSK 3/4 (2 OFDM Symbols)
Modulation RCH PDU	BPSK 1/2 (3 OFDM Symbols)
PHY Overhead (Preamble) in Uplink	4 OFDM Symbols
PHY Overhead (Preamble) in Downlink	2 OFDM Symbols

5.3 Probability of PDU Loss

The Bit Error Rate (BER) on the radio channel is dependent upon the Carrier to Interference (C/I) ratio at the input of the receiver. The same is applicable to the HIPERLAN/2 Channel. In this section the theoretical value of Packet Error Rate (PER) is applicable to the various

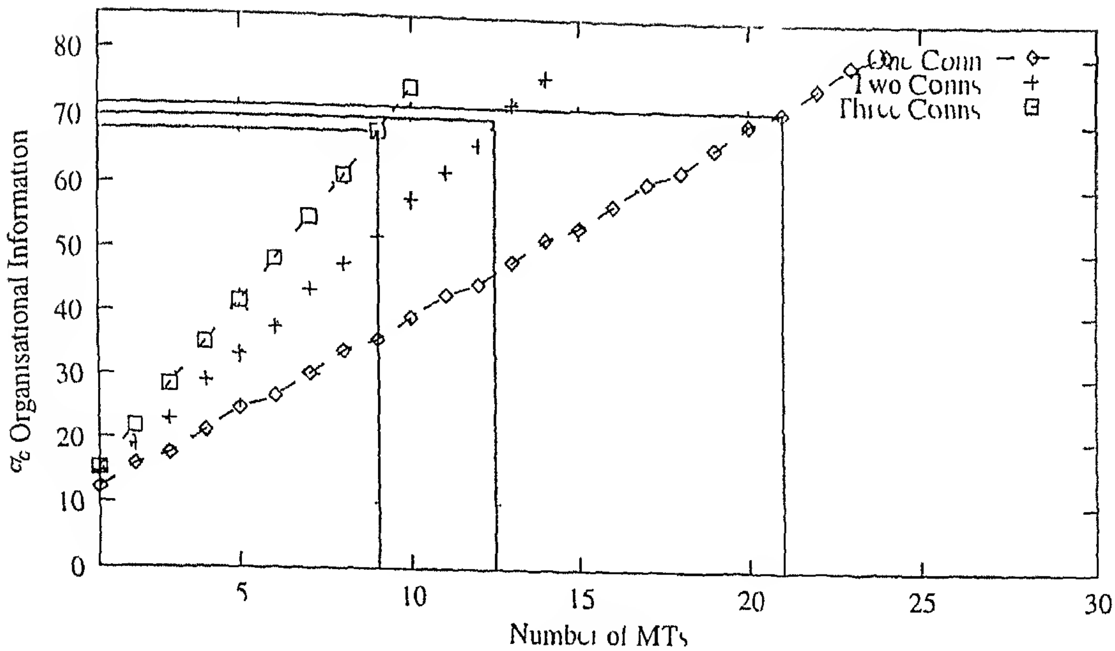


Figure 5.5 Organisational information on conventional link

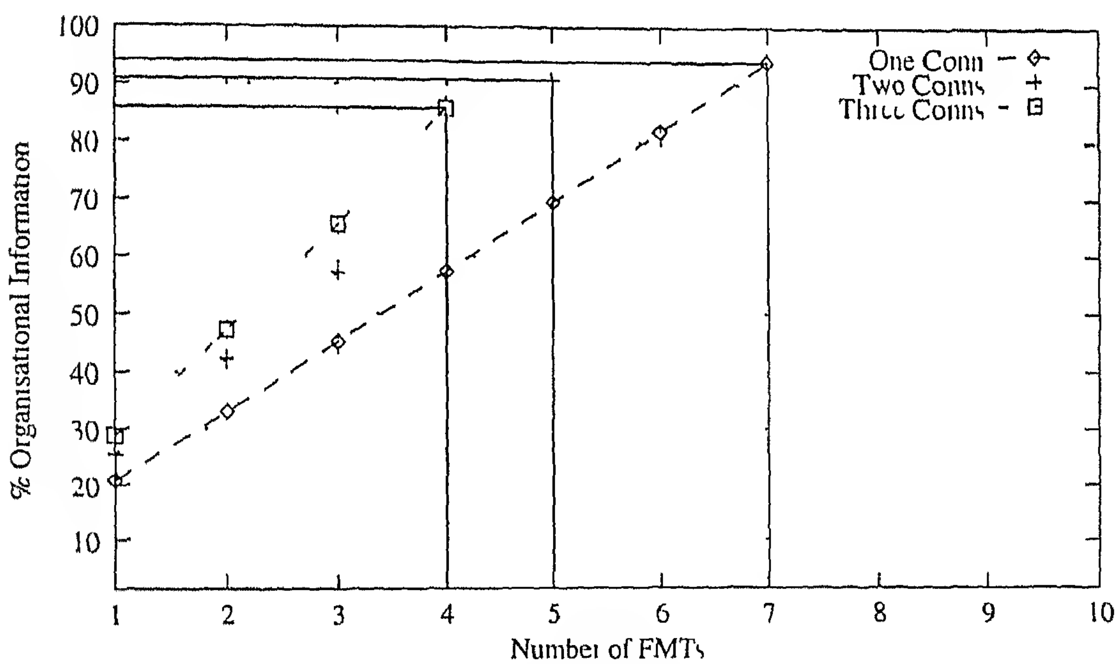


Figure 5.6 Organisational information on forwarding link

PDUs, vis-a-vis probability of errors on the channel has been analysed. The analysis pertain only to the forwarding link. Let the probability of losing a PDU be p, then the probability of receiving a PDU correctly is given by $(1-p)$.

F-BCH PDU The F-BCH PDU on the forward link can get lost due to the loss of BCH and FCH PDUs on the conventional link and also due to its own loss on the forward link.

The F BCH PDU error rate $P(F - BCH_{PDU})$ is given by

$$
\begin{aligned}
\mathbf{P(F - BCH_{PDU})} &= 1 - [(1-p)^3] \\
&= 1 - [1 - p^3 + 3p^2 - 3p] \\
&= p^3 + 3p - 3p
\end{aligned}
\tag{19}
$$

F FCH PDU The F FCH PDU can get lost in the forward link channel or can also be lost due to the loss of F BCH on the forwarding link and the loss of BCH and FCH on the conventional link. Calculating the F FCH PDU error rate

$$
\begin{aligned}
\mathbf{P(F - FCH_{PDU})} &= 1 - [(1-p)^4] \\
&= 1 - [1 - 4p^4 + 6p^3 - 4p^2 + p \\
&= 4p - 6p^2 + 4p^3 - p^4
\end{aligned}
\tag{20}
$$

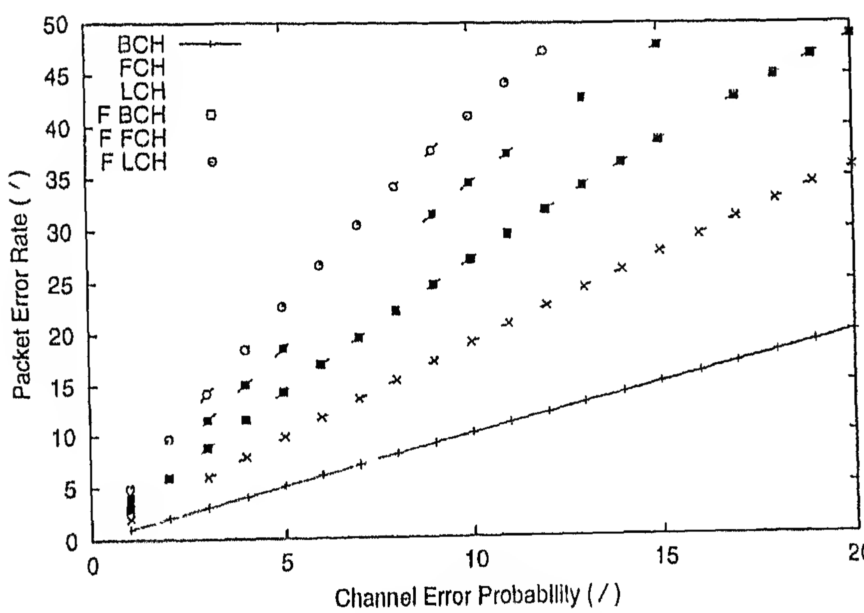


Figure 5.7 Packet Error Rate analysis

F LCH PDU The F LCH PDU can get lost in the forward link channel or due to the loss of F BCH, F FCH, BCH or FCH. Calculating the F LCH PDU error rate in a similar method used above

$$
\begin{aligned}
\mathbf{P(F - LCH_{PDU})} &= 1 - [(1-p)^5] \\
&= 1 - [-p^5 + 5p^4 - 10p^3 + 10p^2 - 5p + 1] \\
&= p^5 - 5p^4 + 10p^3 - 10p^2 + 5p
\end{aligned}
\tag{21}
$$

Graphical Results Using the above derived equations a graphical plot is shown in Figure 5.3. The error probability of losing PDUs in the channel is represented on the x axis and the corresponding calculated Packet Error Rate is plotted on y axis.

It has been assumed that the probability of error on the channel for all the PDUs is same i.e. p. This is not the case in real scenario where the p for each PDU will depend upon the C/I, which is dependant upon the modulation scheme and the coding rate used to transmit the PDU[17].

Chapter 6

Implementation

The first working model of HIPERLAN/2 will be ready at the beginning of 2000. The need for a Forwarder for this basic model was felt and a parallel work to develop a Forwarder was started simultaneously. At this initial stages of the development of the HIPERLAN/2 System, compatibility of the Forwarder with that of the basic models of AP and MT was one of the main constraints.
With all this in mind it was decided to first develop and analyse the Forwarder in its most basic form and thus the *FMT controlled Concept* was chosen. Since the HIPERLAN/2 System is constantly improved upon with additions and deletions to the specifications of the same, this basic model of the Forwarder can also be improved upon simultaneously. This section covers the implemented system in brief and discusses the details of implementation of a FMT controlled concept of forwarding.

6.1 HIPERLAN/2 System

The implemented HIPERLAN/2 simulator has been written in the System Description Language (SDL). The highest level of the system diagram shows five blocks: the block *SimControl*, the blocks *MT*, *AP*, *FMT* and the *Channel* (figure 6.1). Whereas there will be only one instance of the block SimControl and the block Channel at any time, there might be multiple instances of the blocks Access Point (AP), Mobile Terminal (MT) or Forwarding Mobile Terminal (FMT), depending upon the number of MTs, FMTs and the APs in the network. Every AP, MT and FMT in the simulation is represented by one block of the respective type. The blocks of AP, MT and the Channel were developed and analysed with simulations in other thesis of the HIPERLAN/2 Group at this chair (Refer [30] and [11]).

In this thesis, the simulator was redesigned to include a forwarder. The MAC layer of an AP and a MT was revised to handle all the physical modes mentioned in the specifications possible. All other latest changes in the specifications were also implemented. A new traffic

generator capable of generating different types of traffic at various loads was integrated into the simulator. Necessary changes were made in the Link Control (LC) block to handle this traffic generator. The MAC layer was further extended to function as a FMT.

The following subsections bring out the implementation details of each of the constituents and subconstituents.

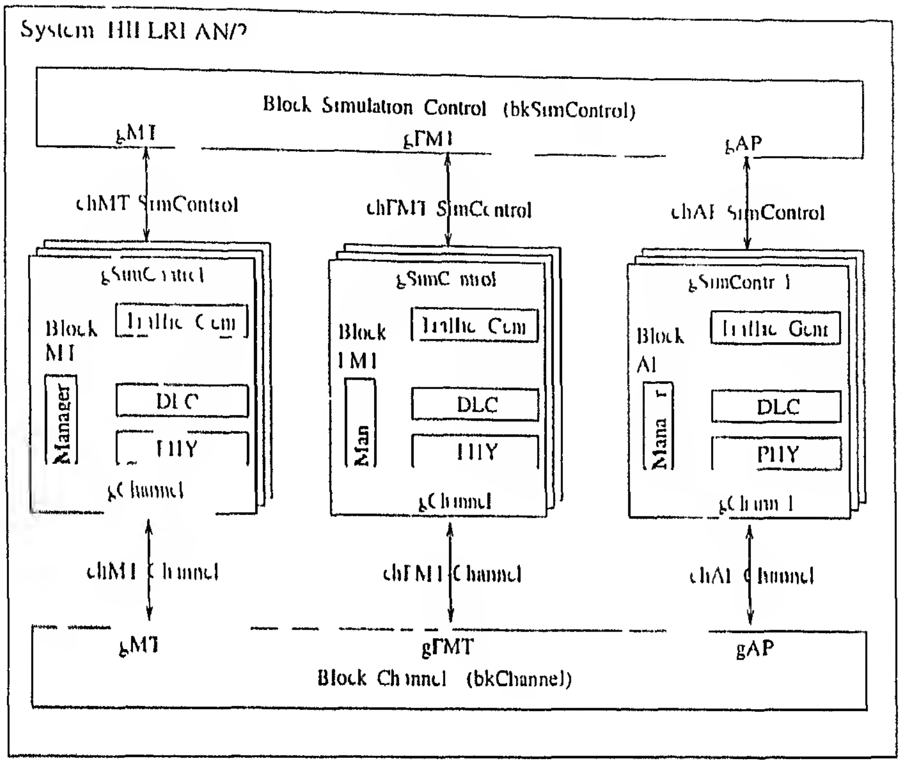


Figure 6.1: System environment in SDL

6.1.1 Block Simulation Control

The block Simulation Control is the heart of the whole system. The main tasks of the SimControl are the initialization, control and the execution of the simulation. At start up all AP and MT/FMT blocks register to the SimControl who then distributes unique *AP* and *Mobile IDs*. Other parameters specific to the simulation to be executed are read from the *default files* using the *Read Default package* available in an internal class library called SIMCO [1]. All these default files and the parameters read are shown in table 6.1. Among these parameters are for instance the number of Access Point Transceivers (APTs) per APC, the number of associated MTs/FMTs in the system, the number of data connections and their respective data rates etc. The use of default files in the SDL allows to run different simulation scenarios with the same compiled version of the program.

6.1.2 Block Channel

The task of the block Channel is to transfer and broadcast the signals from the AP to the MTs/FMTs and vice versa. At start up, the APT creates one Channel instance playing the role of a radio cell. All MTs/FMTs then register to one of these radio cells. During the simulation, the physical layer of the respective MT/FMT keeps updating its position with the channel or we can say in the radio cell. When a handover takes place or while scanning another frequency, the MT will change the serving channel instance. The channel broadcasts the received signals to every entity in a radio cell.

6.1.3 Block AP/MT/FMT

The blocks AP and MT/FMT are further subdivided into four sub blocks that represent the OSI layers 1 (PHY), layer 2 (DLC), a manager and a Traffic Generator. The manager has the only task of initializing the MT/AP. When instructed by the SimControl, the MT manager can also reset the MT by informing all blocks of this MT to set all parameters to their initial values.

6.1.4 Sub-Block PHY

BkPHY represents a Physical layer of the OSI model. The Physical layer contains a process for sending and a process for receiving. The Phy manager gets information like the position, sending power and receiving sensitivity from the file *PhyDefaultList* (Table 6.1). MT mobility is assured by attributing an initial position, a moving direction and the speed to each MT. The physical model that is applied for this HIPERLAN/2 simulator can be found in [30].

6.1.5 Traffic Generator

The Traffic Generator is a SDL Tool developed at the Institute [25], which can generate all types of traffic and a unique output format for every source type. The output format is based on the user's demand, e.g. the user might need the generated traffic in smaller packets as required for ATM. Various instances of the *Constant Bit Rate* (CBR), *Poisson* and *Video* traffic sources can be maintained to generate traffic at varying loads. The output format consists of the originating time, serial number and the length of the packet. The user can make use of these in the analysis.

6.1.6 DLC Layer

The DLC block combines the functionalities of the MAC, the RLC and the EC sublayers. Besides there are blocks for the Scheduler and a DLC manager.

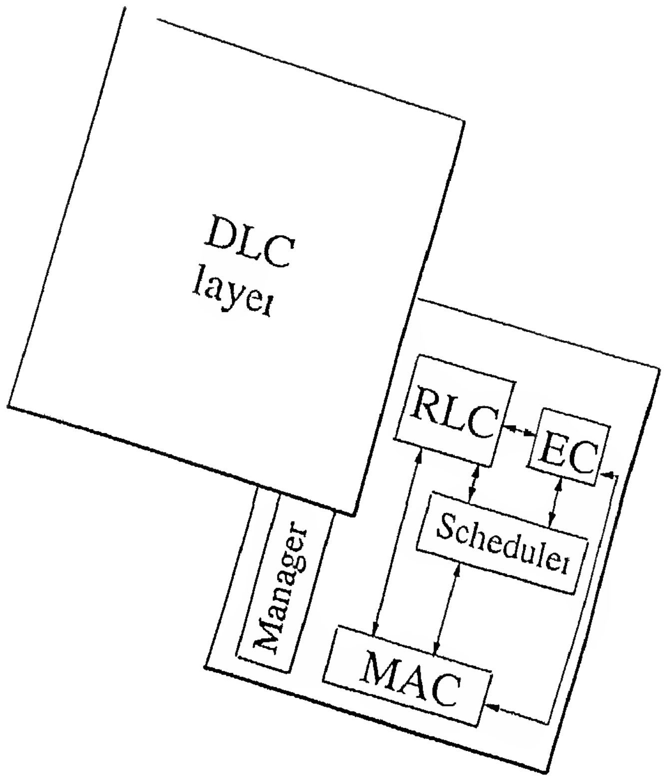


Figure 6.2: The DLC layer in SDL

The DLC manager is again responsible only for the initialization of this layer. Further it collects and redistributes Process IDs (PIDs) in the DLC layer so that communication between different processes is faster. Each sub block consists of one manager process and one or several sub layer instances. Especially on the AP side there might be more than one of these sub layer instances. So for every simulated APT one MAC and one PHY instance will be created, as well as one scheduler instance. The RLC instance on the MT/FMT side will find its peer entity created on the AP side and for every connection that is built up by the RLC, one EC and one traffic generator source instance are created.

The MAC layer, that was subject of another thesis at this chair [11], was adapted and integrated into this HIPERLAN/2 simulator. The EC block is only implemented in a restricted way, i.e. data user connections might be set up and released but no ARQ is regarded. Even the RLC Block is implemented in a similar manner. It was analysed in detail within the other thesis at this chair [30]. As strategy for the scheduler the *non exhaustive variant* of the *Round Robin* method has been chosen for simulations. The results are recorded through a tool developed and build into process LRE evaluation [20].

Default parameters, especially those that configure the AP and the MT/FMT, are read out of different files. There are five such lists. The SDL blocks SimControl, Channel

Physical Layer and DLC Layer use these lists

Table 6.1 Default parameters

Name of the List	Item	Validity
ChDefaultList	operating frequency	APT
	attenuation factor	APT
	noise power	APT
PhyDefaultList	receiving sensitivity	System
	sending power in dBm	MT and APT
	switch for error	System
	initial location	APT
	initial location	MT
	speed in [kmph]	MT
	moving direction	MT
	PER table	System
MAC defaultList	Physical Modes for PDUs	APT and MT
ScenarioDefaultList	Parameters for Simulation	System
	Data rate	System
	Type of Traffic	System
	Select Simulation Scenario	System
SimControlDefaultList	number of APTs	APC
	number of MTs	APT
	MAC Ids to MT	APT and MT
	number of connections per MT	APT and MT

6.2 Implementation of the Forwarder

Block FMT carries out the function of a Forwarder besides acting also as a normal MT. Like other MTs, Block FMT also has four Sub Blocks representing Physical layer, DLC layer, a Manager and a Traffic Generator. The structure of Sub Block bkPHY and Traffic Generator are similar to the other MTs. The Manager's task is again to initialise all the Sub Blocks except that it knows that it has to act as a Forwarder and thus will expect association from RMTs. This functionality is carried out by the Simulation Control. Forwarding involves only the MAC layer, therefore Sub Block bkDLC is different with an additional block in bkForwarder. Except bkLC and bkRLC, the functions of all other Sub Sub blocks are different. These major differences will be explained in subsequent sections.

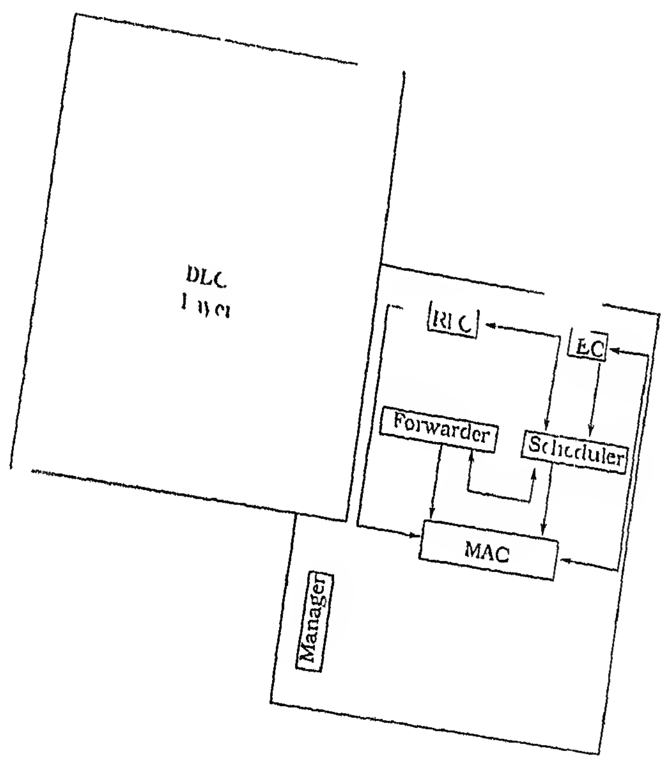


Figure 6.3 Block bkDLC

6.2.1 Sub-Block bkFMT-MAC

The MAC layer of the FMT has to carry out the additional task of forwarding data to the RMTs. The operation of forwarding involves construction of a MAC Sub Frame (SF). The characteristics of this SF have already been explained in Section 4.3.1. In the DL Phase, the FMT picks up data pertaining to all the RMTs associated with it and sends them to Sub Block bkForwarder where it is stored in a queue temporarily for further forwarding.

In the SF's F DL Phase the data stored in this queue is forwarded to RMTs and similarly in the F UL Phase data from RMTs (meant for AP) is collected and once again stored in the queue. This UL data from the queue is forwarded to the AP in the appropriate slots of the MAC Frame

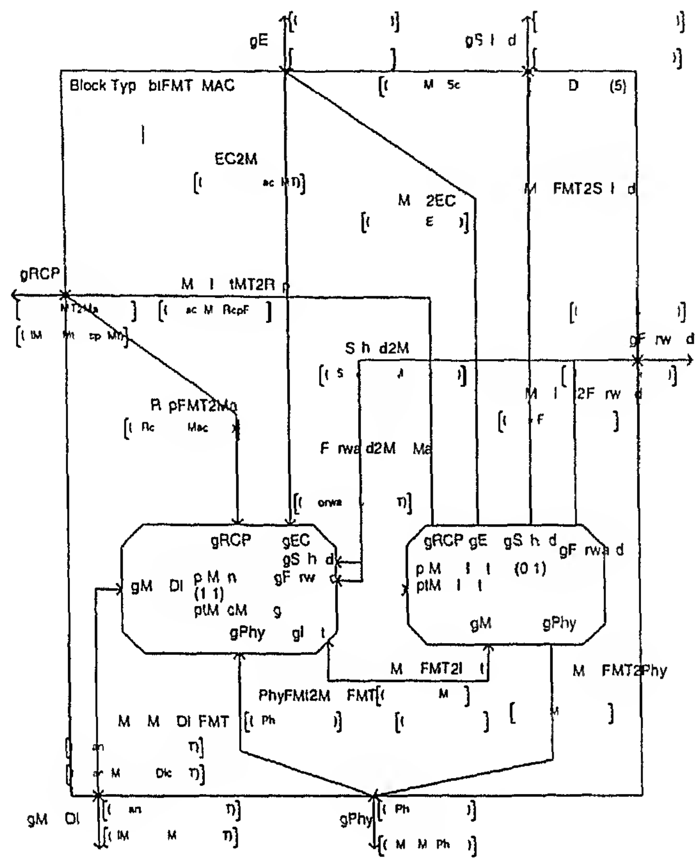


Figure 6 4 Sub Block bkFMT MAC

6 2 2 Sub-Block bkScheduler

The Sub Block bkScheduler has three different processes in Manager, SchedulerMT and the Scheduler, as shown in the Figure 6 5. The Manager differentiates between signals meant for other two processes (ptScheduler and ptSchedulerMT) and thus is just a router of the signals

Process Type SchedulerMT

The function of ptSchedulerMT is similar to that of a ptSchedulerMT of a normal MT. It acts on the Resource Request from the Sub Block bkForwarder and places this request with the AP. The Resource Request includes request for FMT's own UL data, UL data for the

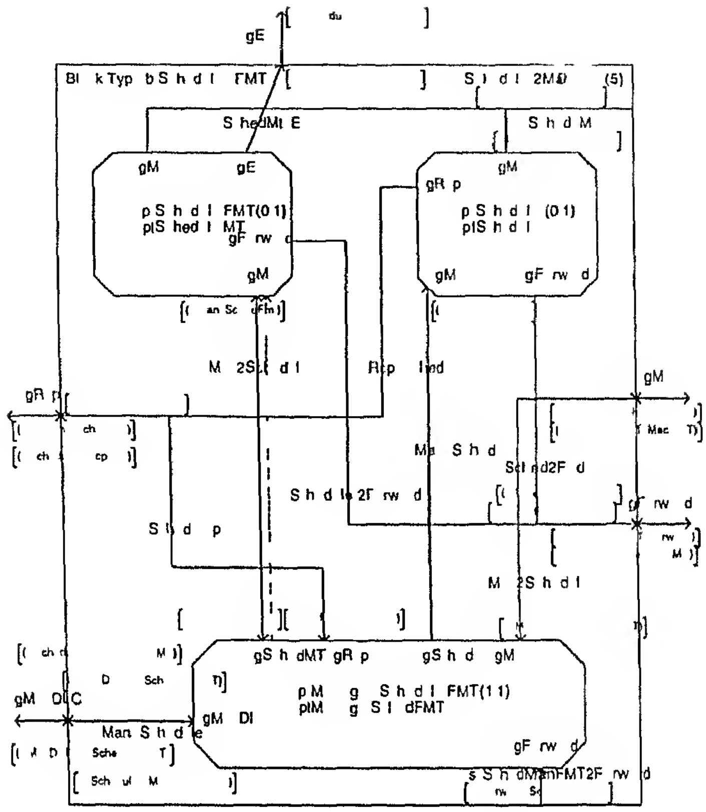


Figure 6 5 Sub Block bkScheduler

RMT s and also the request for the SF In case of no resources granted the request is sent through RACH

Process Type Scheduler

It acts as a Scheduler for the SI Scheduling is done based on the Resource Request for I DL and I UL Phases and any RCP requests The Scheduling is ofcourse restricted by the resources granted for the SI Two different scheduling schemes have been adopted, namely Exhaustive Round Robin and Non Exhaustive Round Robin [11]

6 2 3 Sub-Block bkForwarder

This is the most important Sub Block of the LMT see Figure (6 6) As the name suggests it is involved in forwarding of the data One instance each of bkForward is generated for each User Connection to the RMTs Each of these instances maintain an UL and a DL Queue for the data that has to be forwarded in either direction as suggested by the name of the Queue The functions of this subblock are listed below

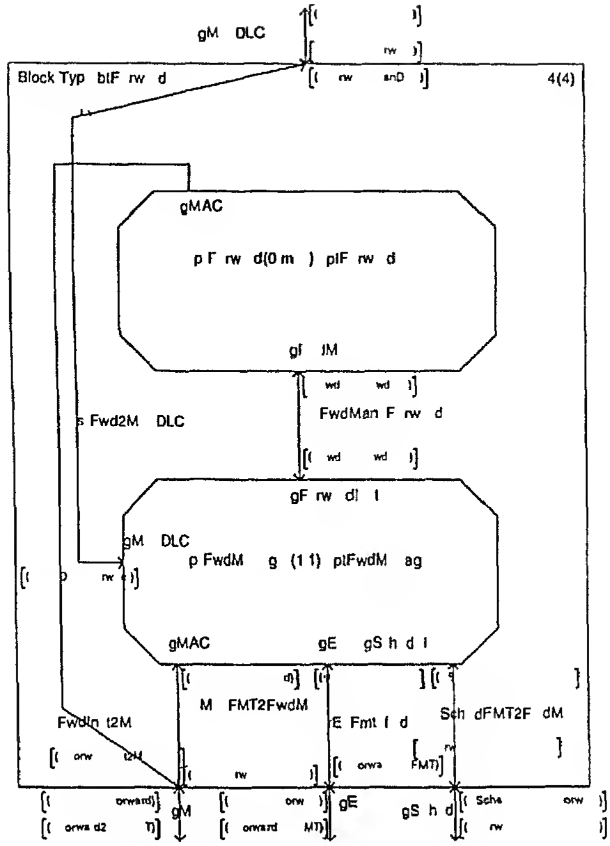


Figure 6 6 Sub Block bkForwarder

- **Resource Requests**

  It compiles and updates various Resource Requests needed for the functioning of the FMT These are summarised as below

  - **F DL Request**

    F DL request is for the F DL Phase i e data that has to be forwarded from the AP to the RMT It is based on the data stored in the DL Queues in the respective instance of Process type ptForward

  - **F UL Request**

    F UL Phase corresponds to this request and is based on the Resource Request sent by the RMTs

  - **Own UL Request**

    The request is compiled from UL data in the FMT higher layer (Sub Block bkEC) that is waiting to be sent to the AP This will exist if the FMT is also

functioning as a normal MT

- RMT UL Request

  This is the data that has been stored in the UL Queues in the respective ptForward and has to be forwarded to the AP

- **Data Queues**

  As explained above each instance maintains an UL and a DL Queue where the data is stored temporarily till the time it is forwarded. An important issue here is the length of these queues which require memory space in the hardware. Analysis has also been done for this and is discussed in one of the following chapters

Chapter 7

Simulations and Results

The simulations were carried out in the HIPERLAN/2 Simulator at this chair. This chapter discusses various simulation scenarios adopted and the analysis based on the results from these simulations. The analysis is then compared with the theoretical results in the previous chapter.

The simulations were aimed at the following:

- Check end to end Cell Delay experienced from the AP to RMT
- Verify maximum System Throughput
- Analyse System Throughput vis a vis System Load
- Analyse the Packet Error Rate on the erroneous channel
- Verify system stability on an erroneous channel

The purpose of the simulations was to judge:

- Quality of Service
- Efficiency of the system (Protocols adopted)
- Verification of theoretical analysis

The main purpose of the simulations was to verify the correct functioning of a forwarder and analyse it for performance evaluation. There were three main scenarios adopted namely:

- **Validation Simulation Scenario**
  The purpose of this simulation was to validate correct functioning of a FMT as a normal MT. The results have been compared with those in the other thesis [11].

- **Network Simulation Scenario**

  As the name suggests this scenario is aimed to verify the correct functioning of a FMT in a network in one radio cell The network consists of an AP one to six FMTs and one to six RMTs

- **High Load Simulations**

  In this scenario the simulations in the previous case were repeated to handle high loads The aim was system stability on higher loads The system set up is the same as in the previous scenario

7 1 Validation Simulation Scenario

The system was established with one APT one FMT associated to the AP and one RMT further associated to the FMT as shown in Figure 7 1

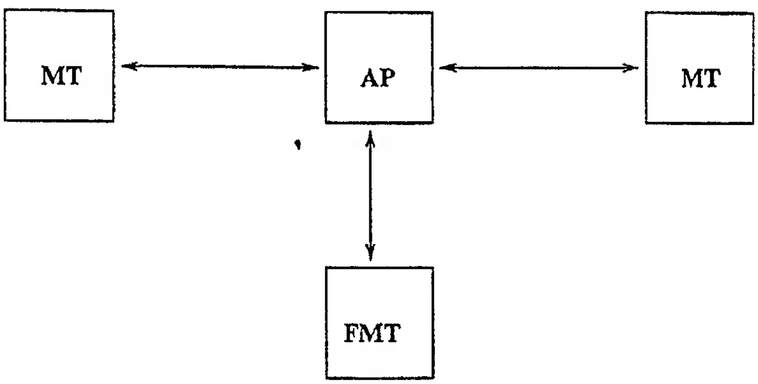


Figure 7 1 Validation simulation scenario system setup

Purpose The simulations were done to check compatibility of the FMT with the AP and the MT specifications and thus verify the correct functioning of FMT as a normal MT

Parameters The various parameters involved in the validation scenario are tabulated in Table 7 1

Results The parameter compared was the mean cell delay The graphs show the plot of the distribution function of the cell delay Figure 7 2 has been taken from the thesis on the MAC layer [11] The corresponding plots from this simulations are shown in Figure 7 3 The exact nature of the graphs and the almost same mean cell delay confirm the compatibility and the option to use a FMT as a normal MT

Table 7.1 Validation simulation scenario parameters

Parameter	Value
Network Setup	1 AP 2 MTs and 1 FMT
User Connection	One connection to each FMT and MT for both Uplink and Downlink
Number of hops	One
Number of RACH slots	Four
Modulation BCH PDU	BPSK 1/2 (5 OFDM Symbols)
Modulation ACH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation LCH PDU	16 QAM 3/4 (3 OFDM Symbols)
Modulation FCH PDU	BPSK 1/2 (9 OFDM Symbols)
Modulation SCH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation RCH PDU	BPSK 1/2 (3 OFDM Symbols)
PHY Overhead (Preamble) in Uplink	4 OFDM Symbols
PHY Overhead (Preamble) in Downlink	2 OFDM Symbols
Scheduling Strategy	Round Robin Non Exhaustive
System Load	1 Mbps to 25 Mbps
Type of Traffic	CBR, Poisson and Video
Channel error	None

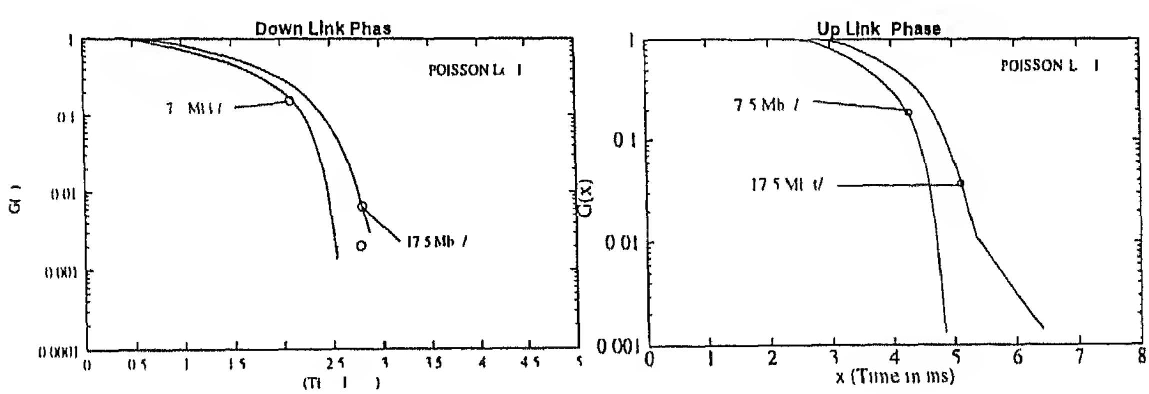


Figure 7.2 Mean cell delay in other thesis [11]

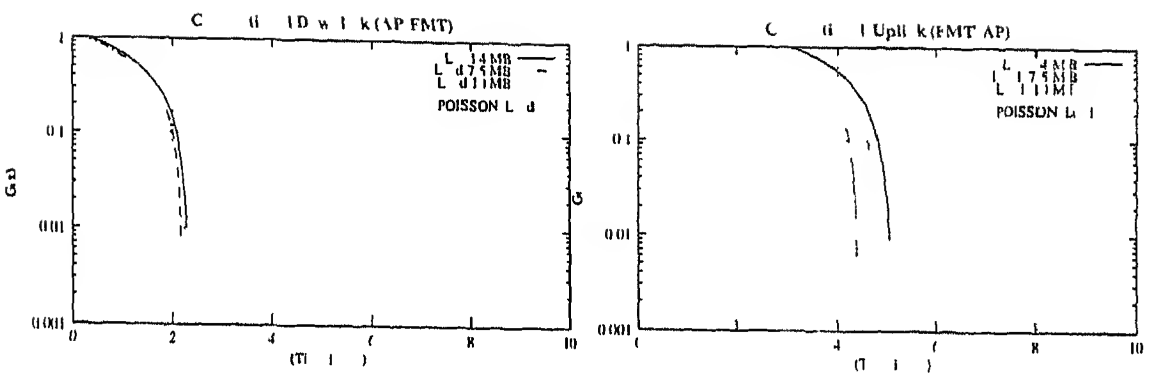


Figure 7 3 Mean cell delay in this simulation

7.2 Network Simulation Scenario

The network simulation scenario was the most basic simulation done with the system established with one APT, one to six FMTs and one to six RMTs associated to the AP. Each FMT had one RMT associated to it.

The simulations were divided into three parts to verify cell delay, throughput and the Packet Error Rate (PER). All these have been presented in the succeeding sections. Some of the important points and parameters pertaining to the simulations are listed below.

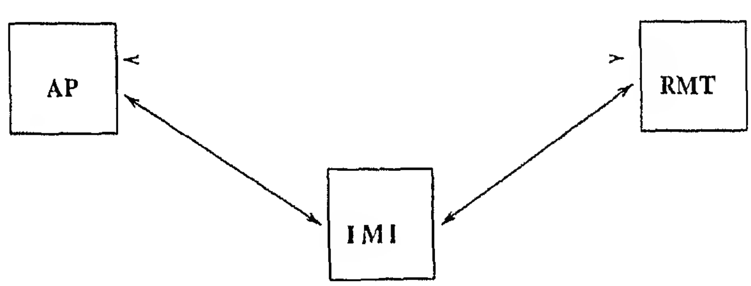
Purpose The simulations were done to verify the correct functioning of FMT as a forwarder and to analyse the points mentioned at the beginning of this chapter.

Method A MT was placed at a large distance, out of range of the AP. This MT acted as a RMT and was associated to the FMT. The FMT forwarded data to the RMT. Both FMT and RMT had one user connection each.

Parameters The various parameters involved in the simulations are tabulated in Table 7.2.

7.2.1 Mean Cell Delay

The system set up for measuring the mean cell delay is shown in Figure 7.4.



AP ACCESS POINT
FMT FORWARDING MOBILE TERMINAL
RMT REMOTE MOBILE TERMINAL

Figure 7.4: System setup for mean cell delay

Two models of the system were prepared and simulated. The model developed initially was the most robust but lacked in performance. The mean cell delay experienced (from RMT to an AP) was not impressive and therefore the second model was designed with a view to improve this delay. The design varies only in the strategy adopted in handling of the Resource Request (RR) at the FMT.

Table 7.2 Simulation Parameters

Parameter	Value
Network Setup	1 AP, 1 - 6 FMTs and 1 - 6 RMTs
User Connection	One connection to each FMT and RMT for both Uplink and Downlink
Number of hops	One
Conventional Link Parameters	
Number of RACH slots	Four
Modulation BCH PDU	BPSK 1/2 (5 OFDM Symbols)
Modulation ACH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation LCH PDU	16 QAM 3/4 (3 OFDM Symbols)
Modulation FCH PDU	BPSK 1/2 (9 OFDM Symbols)
Modulation SCH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation RCH PDU	BPSK 1/2 (3 OFDM Symbols)
PHY Overhead (Preamble) in Uplink	4 OFDM Symbols
PHY Overhead (Preamble) in Downlink	2 OFDM Symbols
Scheduling Strategy	Round Robin Non Exhaustive
Forward Link Parameters	
Number of RACH slots	One
Modulation BCH PDU	BPSK 1/2 (5 OFDM Symbols)
Modulation ACH PDU	BPSK 1/2 (3 OFDM Symbols)
Modulation LCH PDU	64 QAM 3/4 (2 OFDM Symbols)
Modulation FCH PDU	BPSK 3/4 (6 OFDM Symbols)
Modulation SCH PDU	BPSK 3/4 (2 OFDM Symbols)
Modulation RCH PDU	BPSK 1/2 (3 OFDM Symbols)
PHY Overhead (Preamble) in Uplink	1 OFDM Symbols
PHY Overhead (Preamble) in Downlink	2 OFDM Symbols
Scheduling Strategy	Round Robin Non Exhaustive
System Load	1 Mbps to 25 Mbps
Type of Traffic	CBR, Poisson and Video
Channel error	Nil

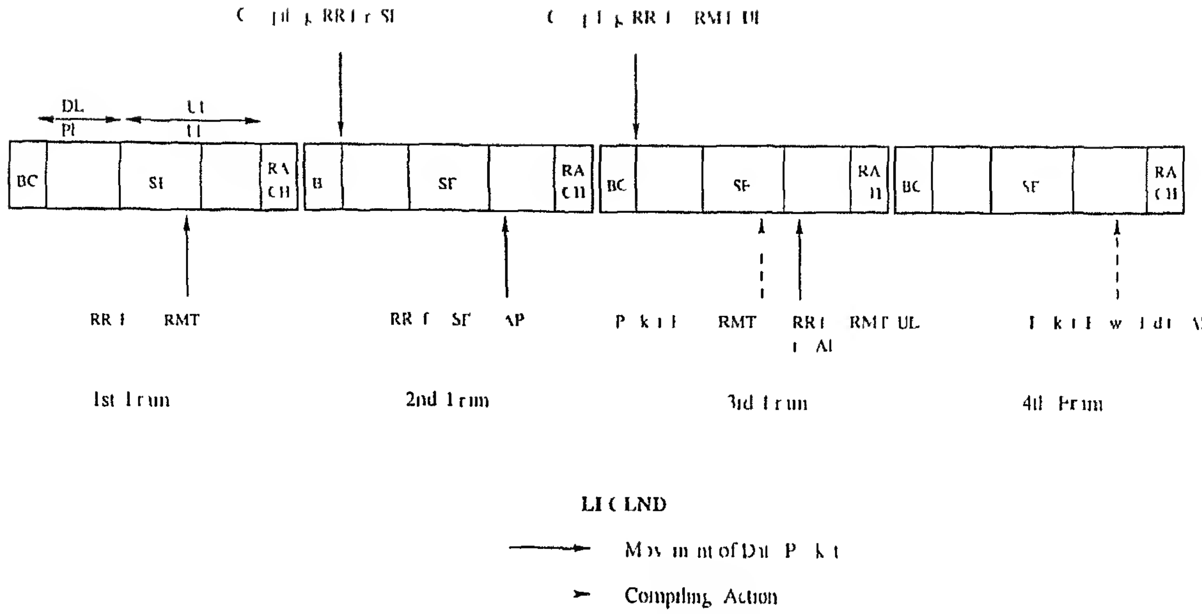


Figure 7.5 Initial system design

Initial System Design

The initial design followed the strategy that the FMT/RMT must finish all the necessary compiling routines for the current frame at the end of the BC phase. This implies that the FMT/MT should compile the RR required for the next MF. Once the downlink phase starts only the polling of appropriate PDUs in the MF is done. The necessary actions and the sequence of events is highlighted in Figure 7.5. In the first MF the RR from a RMT reaches the FMT. After receiving the BC phase in the 2nd MF the FMT then compiles the combined(own RR plus RR for MAC SubFrame) RR. This RR is sent to the AP in the 2nd MF itself. The RGs for the SF is thus done in 3rd MF. Based on this RG a FMT is able to transmit a SF and a receives data packets in the F UL phase from the RMT. The FMT forwards these data packets to the AP in the 4th MF. The complementary distribution function for the mean cell delay is shown in Figures 7.7 and 7.6.

The results show that a packet from a RMT takes approximately three and a half MFs to reach an AP and takes about two MFs in the down link direction. The results for both up link and down link on the conventional link between an AP and a FMT, were compared with that of the thesis on MAC layer done earlier [11]. The results were identical to the results in the referenced thesis and this validates the option to use a FMT like a normal MT.

Improved System Design

The main aim of this design was to reduce the mean cell delay from a RMT to an AP. Figure 7.8 explains the reduction of one MF for the data to reach an AP as compared to the previous design. Like in the previous case, the RR from a RMT reaches the FMT in

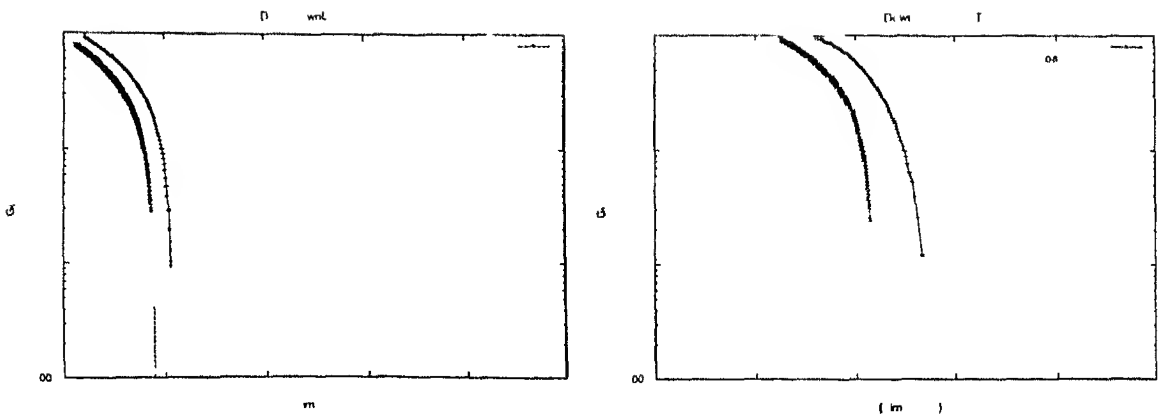


Figure 7 6 Mean cell delay in the down link phase

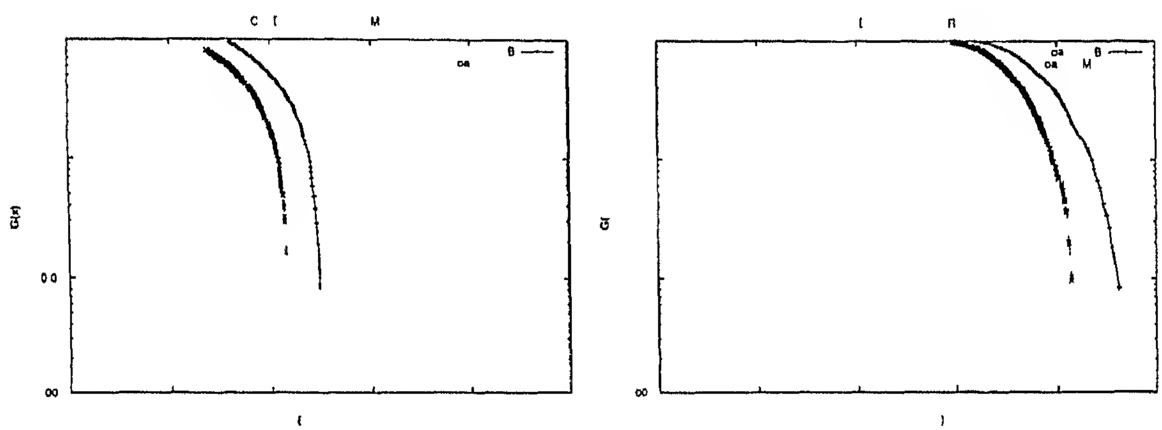


Figure 7 7 Mean cell delay in the uplink phase

the SF of the 1st MI But instead of compiling the RR for the next SF at the beginning of the next MI, the 1 MI now does this work at the end of the same SF With this action the 1 MI is able to send the RR for the next SF in the 1st MI itself The remaining actions are carried out in the 2nd and 3rd MI Thus in this design the actions of 1st and 2nd MIs of previous design are combined into one MI i e 1st MI

POISSON Load The results from this design are shown in Figures 7 10 and 7 9

VIDEO Load The system was also subject to the video type of traffic Table 7 3 highlight the characteristics of the video load Results from this simulation are shown in Figures 7 11 and 7 12

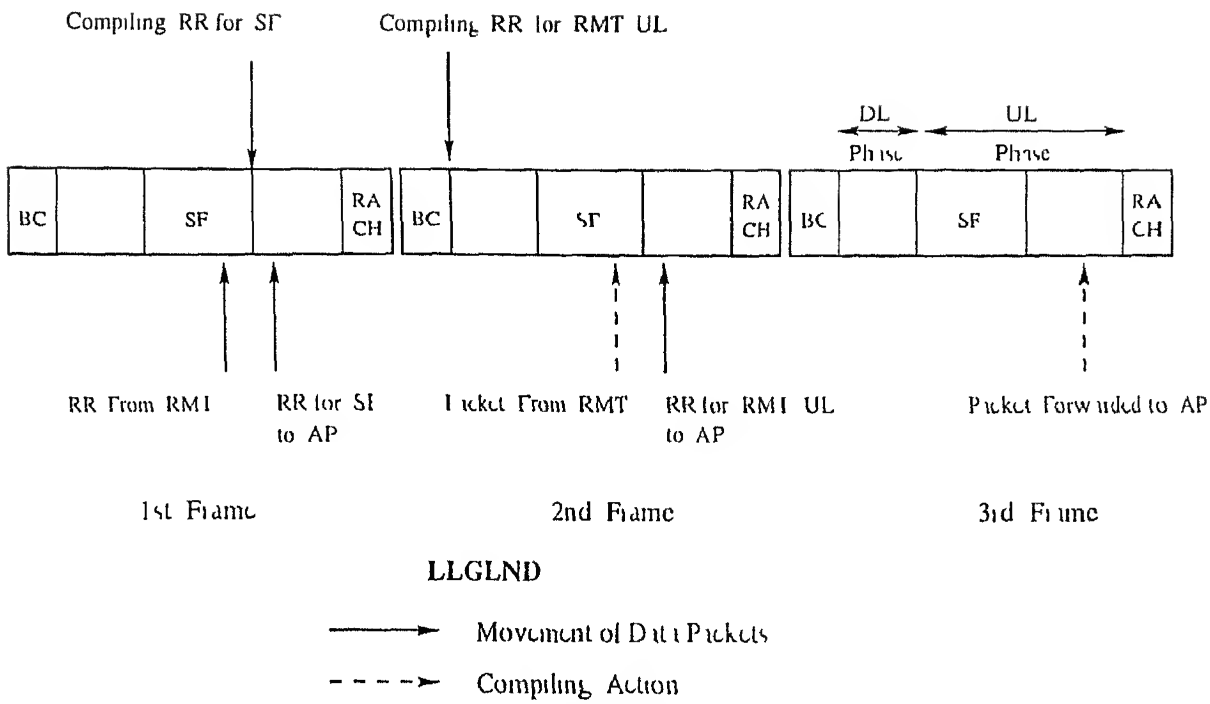


Figure 7.8 Improved system design

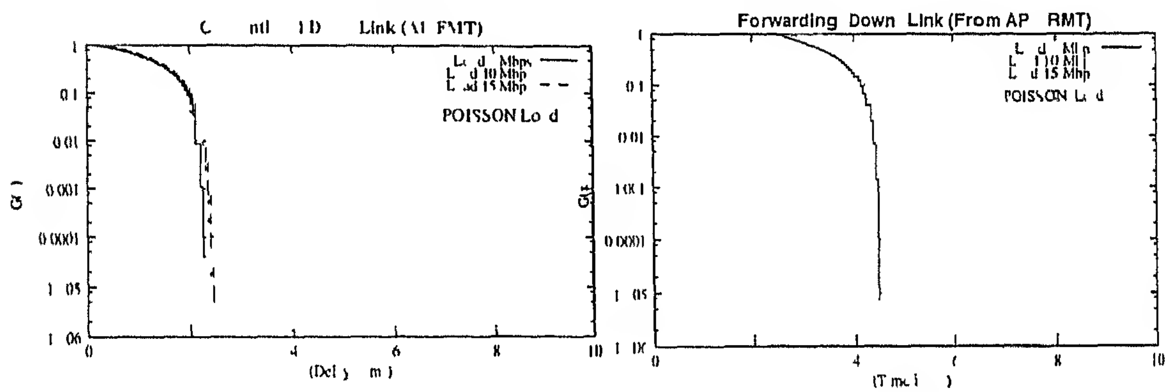


Figure 7.9 Cell delay distribution in downlink phase POISSON load

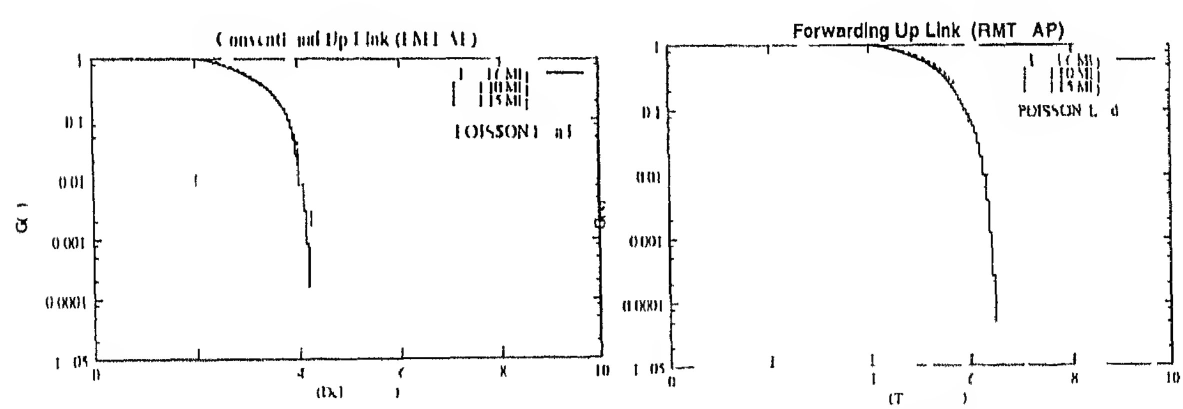


Figure 7.10 Cell delay distribution in uplink phase POISSON load

7.2.2 Throughput Simulations

Two scenarios were considered to measure simulated throughput. Scenario I is shown in Figure 7.13. Six FMTs are associated to the AP and each FMT has one associated RMT,

thus there are total of 12 MTs (FMTs and RMTs) associated to the AP. Figure 7.14 shows the scenario II with one AP, one FMT and 11 RMTs associated to the FMT. The FMT and its associated RMTs constitute a sub-network. This scenario was considered to judge the performance of a FMT in a sub-network.

Table 7.3 Parameters for Video Load

Parameter	Value
Load	4, 15 and 21 Mbps
Number of pictures per second	25
Resolution of picture (rows*columns)	320*240 pixels
Number of bits per pixel	24
Coding	MPEG

The parameters used in this simulation are the same as listed in Table 7.2. The system was configured to run at various system loads from 1 to 25 Mbps. The simulations were divided into three parts.

- System throughput vs system load

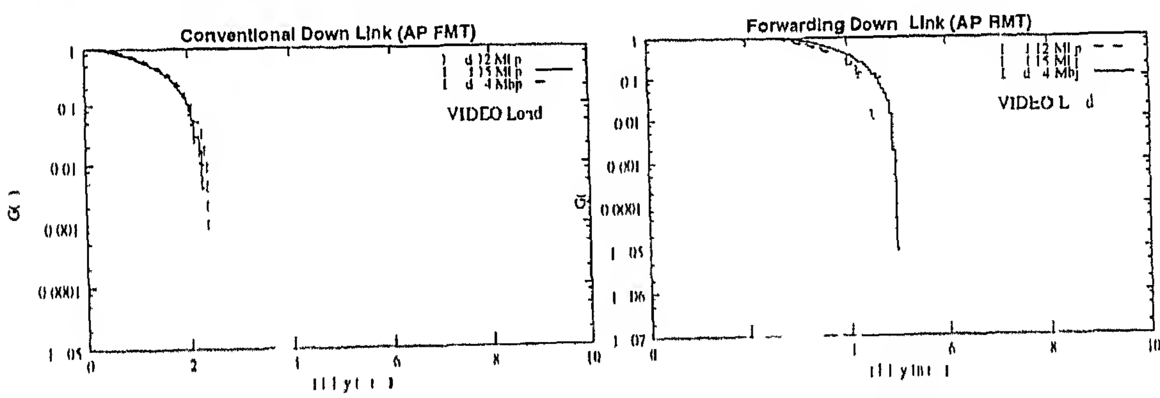


Figure 7.11 Cell delay distribution in downlink phase VIDEO load

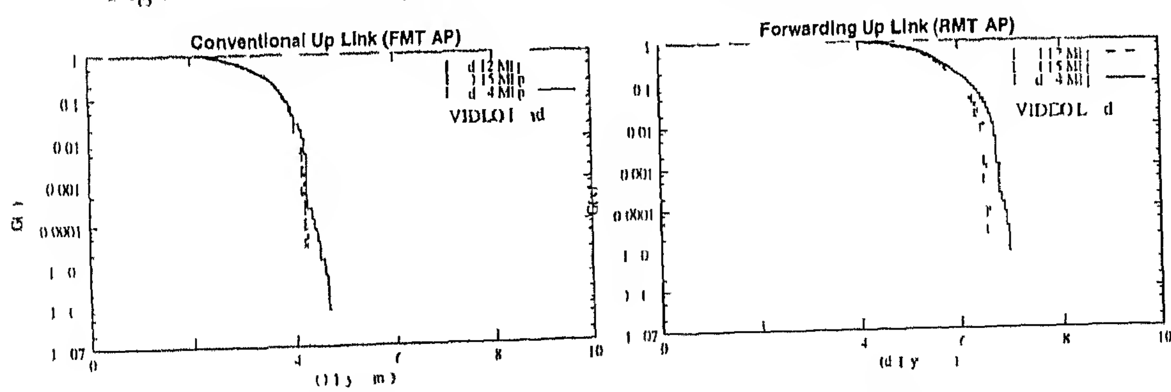


Figure 7.12 Cell delay distribution in uplink phase VIDEO load

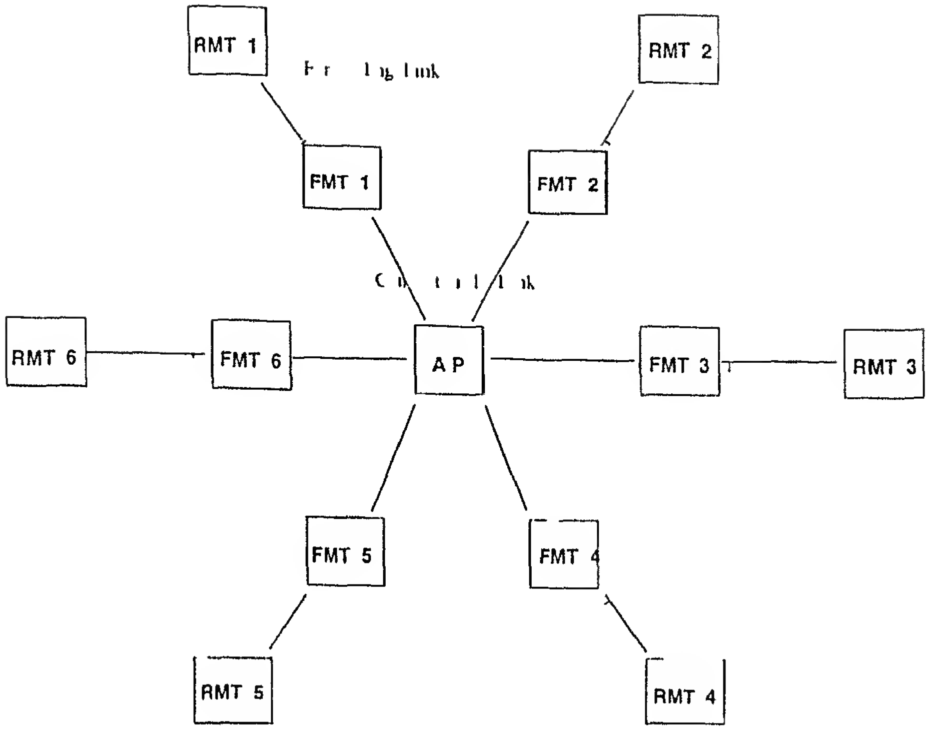


Figure 7.13 System setup for network simulation scenario Scenario I

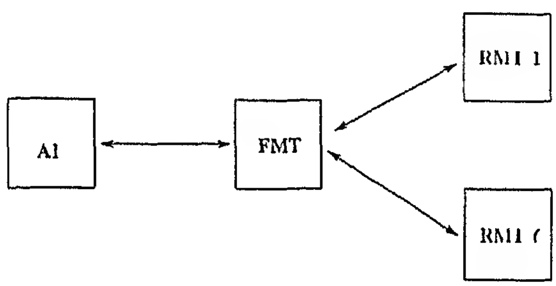


Figure 7.14 System setup for network simulation scenario Scenario II

- Verification of maximum system throughput
- Affect of increasing system load on the mean cell delay
- **System Throughput vs System Load**

The simulations at each system load were done over a period of 10 seconds (5000 MAC frames). The total number of LCH PDUs transmitted and received at each terminal were noted. Throughput was thus calculated for different loads. The number of FMTs and RMTs was also varied from 1 to 6.

Figure 7.15 shows a graph plotted for the system throughput versus the system load for a different number of RMTs. On the x axis is the system load and the resultant simulated throughput is plotted on the y axis. The graph is linear till the time the system is not overloaded. Thereafter any further increase in the load results in constant throughput. The simulated throughput is less than the system load at every

point because of the overheads in the LCH PDU. As far as load is concerned, a LCH PDU has 54 bytes, whereas out of this the useful payload is only 48 bytes.

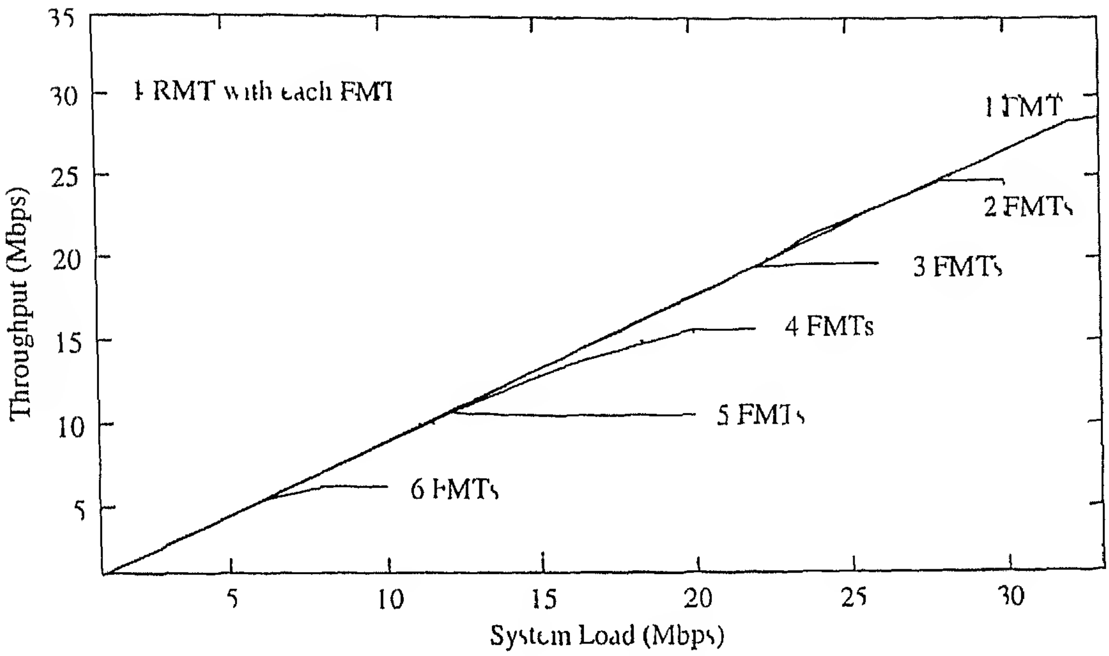


Figure 7.15: System load vs system throughput - Scenario I

For instance, in the case when only one FMT and one RMT is associated to the AP, system throughput increases till 28 Mbps and is constant thereafter. The result is also dependant upon the scheduling strategy used. If the queues are allowed to keep building as the traffic from the user is flowing continuously, the system will run till the time the queue buffers are full and thus run out of memory. This will result in an increasing cell delay as the service waiting period for the packets in the queues is very long. The system behaviour is unspecified from here on. It can only be kept in boundaries considering some QoS parameters described in Section 7.3.

- Maximum Throughput

The simulations also allow calculation of a maximum system throughput at different loads and for varying number of FMTs. This has been shown in Figure 7.16. The graph is plotted with the number of FMTs on the x axis and the maximum system throughput on the y axis. A combination of one FMT and one RMT gives the maximum throughput of approx 28 Mbps and the minimum of approximately 7 Mbps results from a combination of 6 FMTs in Figure 7.13. The maximum throughput can also be seen from Figure 7.15, where its value is represented by the point when the curve stops increasing and turns parallel to the x axis. This simulated result has also been compared with the theoretical throughput (refer Figure 5.3). The difference

between the theoretical and the simulated result is very small because the theoretical calculations do not take into account the access to the RACH and also the possible collisions which can cause delay in sending resource request to the AP. Also at peak load all the MTs may not get service in each frame and thus the access to the RACH increases. The difference shown in the figure has been slightly increased to differentiate between the two curves.

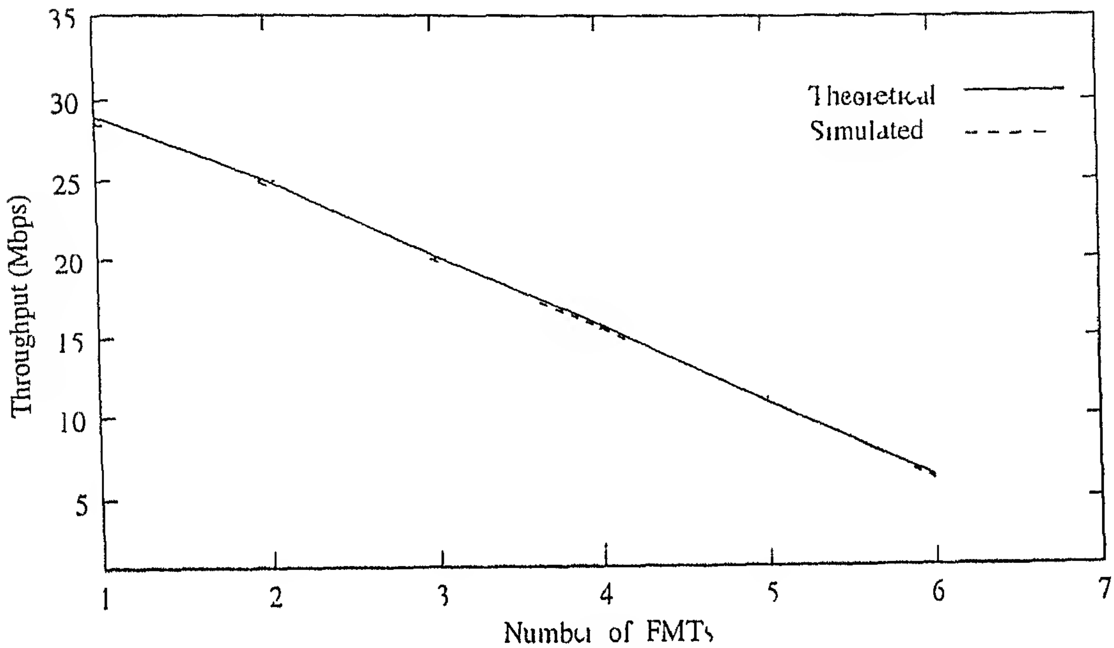


Figure 7.16: Maximum system throughghput – Scenario I

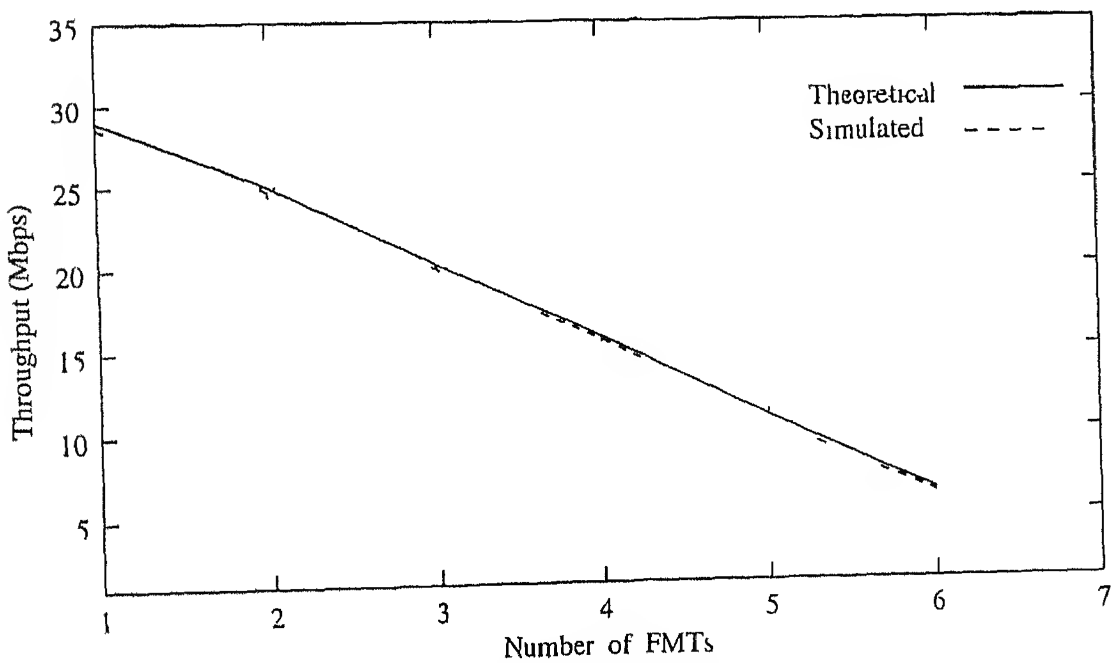


Figure 7.17: Maximum system throughghput – Scenario II

- Cell Delay vs System Load

Figures 7 18 and 7 19 show graphs plotted for the mean cell delay between an AP and a RMT on the y axis against the system load on x axis The mean cell delay is constant till the time the system is not overloaded Beyond the peak load the cell delay starts increasing without any limits At this stage the length of the data queues keeps increasing as the traffic from the user is still flowing The data packets have now have to wait till the time they are serviced Since the throughput is constant the waiting period for the cells continue to increase till the queue has no more place for buffering the incoming packets The system will either start discarding packets from here on or will have an unspecified behaviour The graphs have been shown for varying number of FMTs (from one to six with each having one RMT)

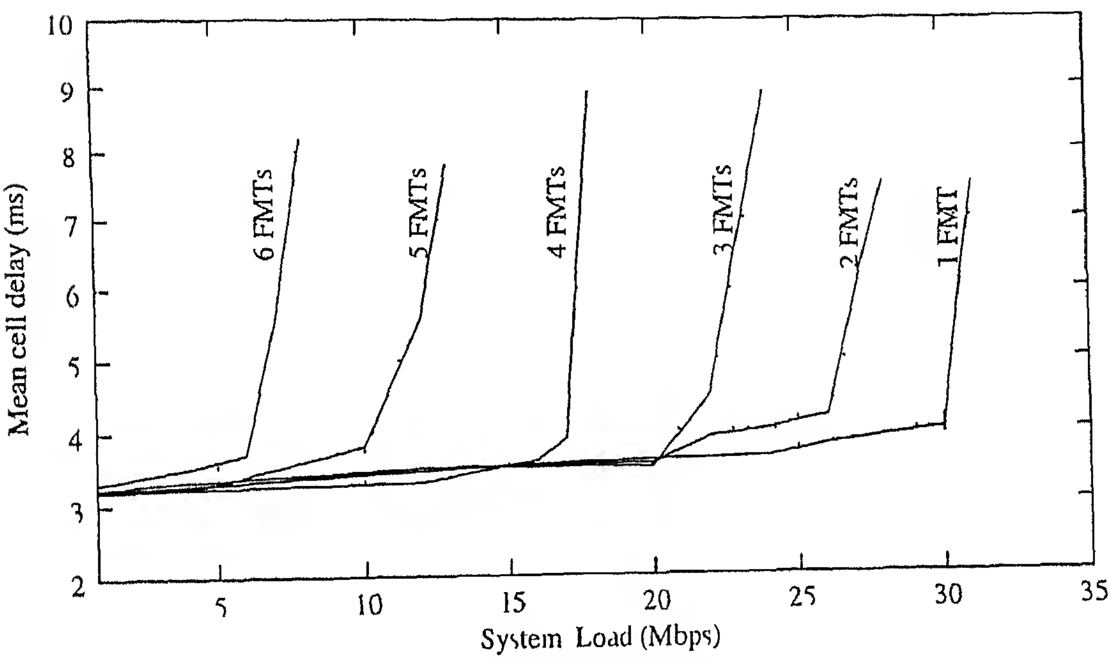


Figure 7 18 Mean downlink cell delay vs system load

7 3 Highload Simulations

It has been highlighted in the previous section that the system behaves as expected till the time it reaches the peak load Beyond this point we get unacceptable results and some strategy has to be adopted to control and thus specify the system behaviour In this thesis two startegies were adopted to handle high loads

- **Limited Data Queue Length**
  The data queues will accept traffic from the user till a limited number of packets are waiting to be serviced as specified in the system Once the length of the queue reaches

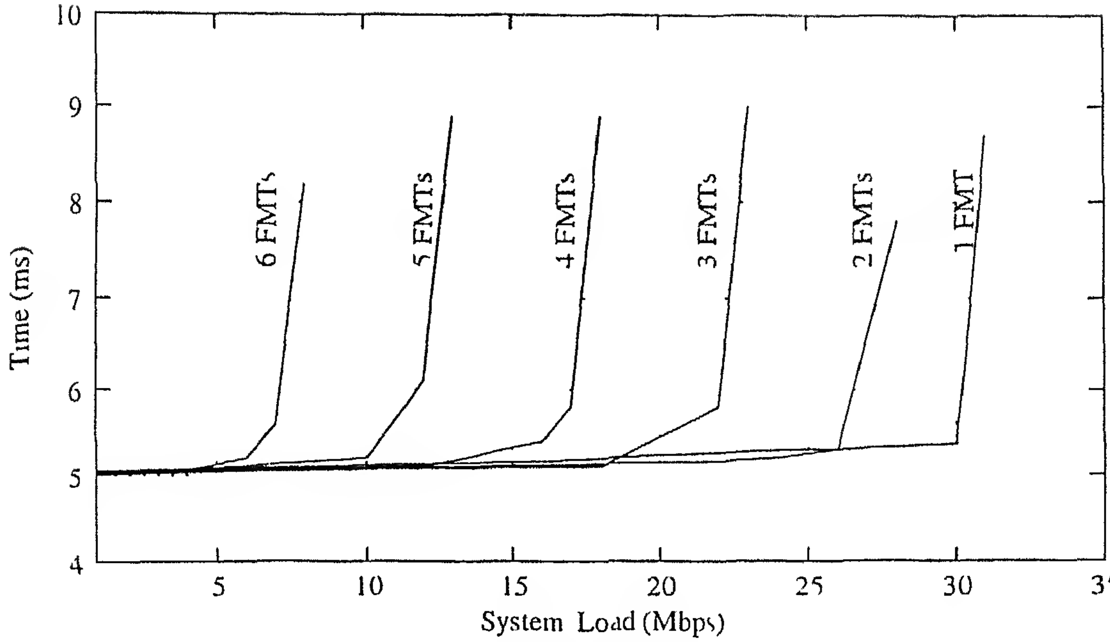


Figure 7 19 Mean uplink cell delay vs system load

the specified value and when a new packet is received the packet to be serviced next is discarded from the queue and the new packet is accepted Thus at any given time the length of the queue is fixed and contains the most recently received packets from the user

- **Limited Service Waiting Period**

  The second strategy adopted was to limit the service waiting period in the queue When a new packet arrives and if the packet to be serviced next has already waited beyond the service time specified it is discarded from the queue and the newly arrived packet is accepted

The system was modified for both the strategies and the simulations were repeated twice In one case the queue lengths were limited to have 50 data packets at any time according to the first strategy For the second strategy the maximum allowable service waiting period was fixed at 15 ms The results of both the strategies followed a similar pattern though the resultant values are different Therefore only the results of the second strategy have been presented here

- **System Throughput versus System Load**

The graph in Figure 7 20 is plotted with system throughput on x axis and system load on y axis The plot shows six curves one each for an increasing number of FMTs (from 1 to 6) with each FMT having one RMT associated to it The throughput

increases linearly till the peak load. Any further increase in system load results in constant throughput.

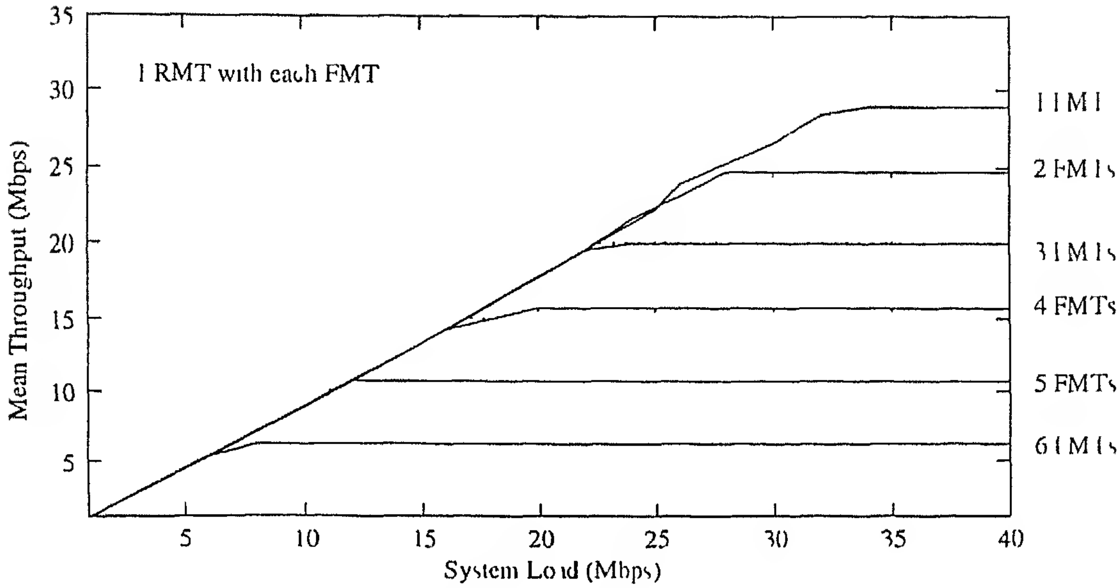


Figure 7.20 System throughput vs system load

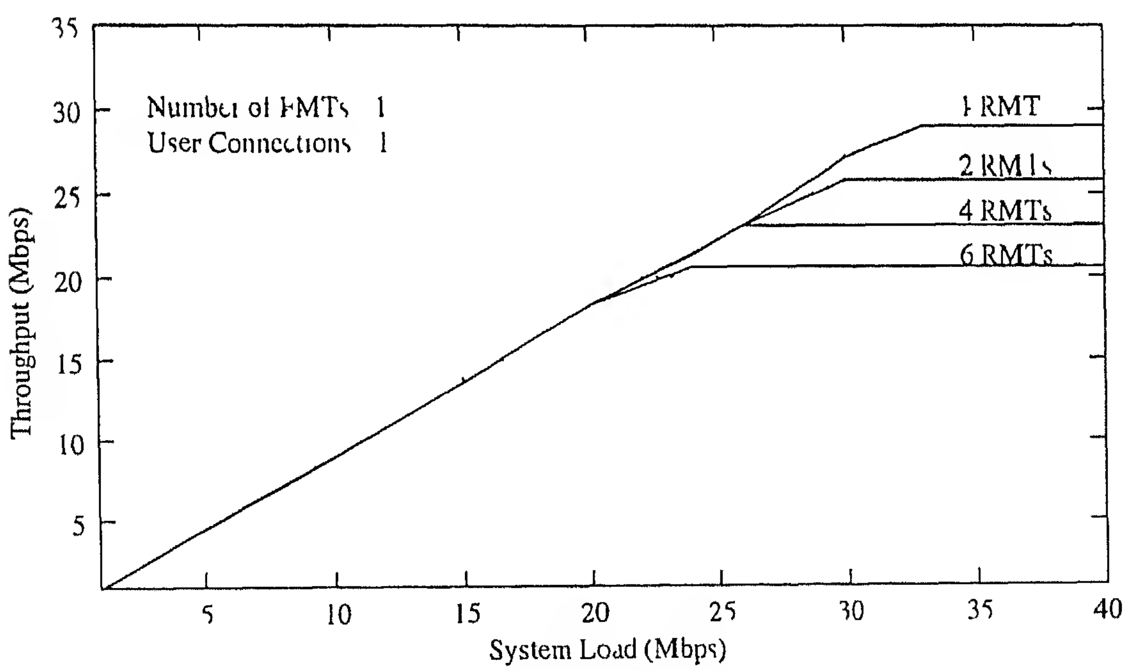


Figure 7.21 System load vs system throughput – Scenario II

- **Mean Cell Delay**

There was a tremendous affect on the mean cell delay due to the new strategy. The results are shown in Figure 7.22 and 7.23. The delay is constant till the peak load and increases to a constant value. But at extreme high load the delay starts reducing

- Cell Loss

The cell loss will increase when the system load is beyond the peak load. The simulation result for the cell loss against the system load is plotted in Figure 7.24. The system load is plotted on x axis and the percentage cell loss is plotted on y axis. The loss is zero till the peak load and increases considerably beyond that. At system load greater than the peak load the throughput of the system reaches its maximum value and thus the service waiting period of the data packets increase. This results in more and more loss in the cells from the queue.

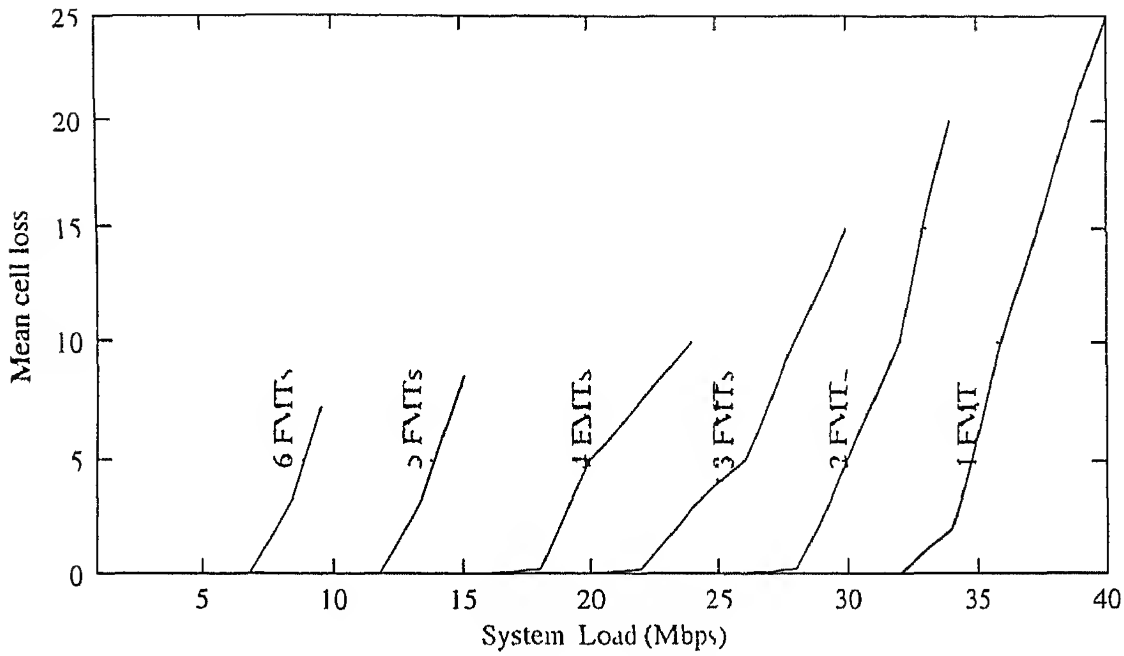


Figure 7.24: Cell loss vs system load

- **PDU Error Rate**

The last set of simulations were done to verify the stability of the system on an erroneous channel. Errors were introduced on the channel and the corresponding losses in the PDUs were noted. The system was stable under these conditions.

7.4 Second Hop Relay

The system was further modified for functioning on multiple hops. The changes in the simulation control included the association of second hop FMTs. The system was established as shown in Figure 7.25. The simulations were done for both poisson and video traffic. The complementary distribution function for the cell delay is shown in Figure 7.26.

Figure 7.25 Cell loss vs system load

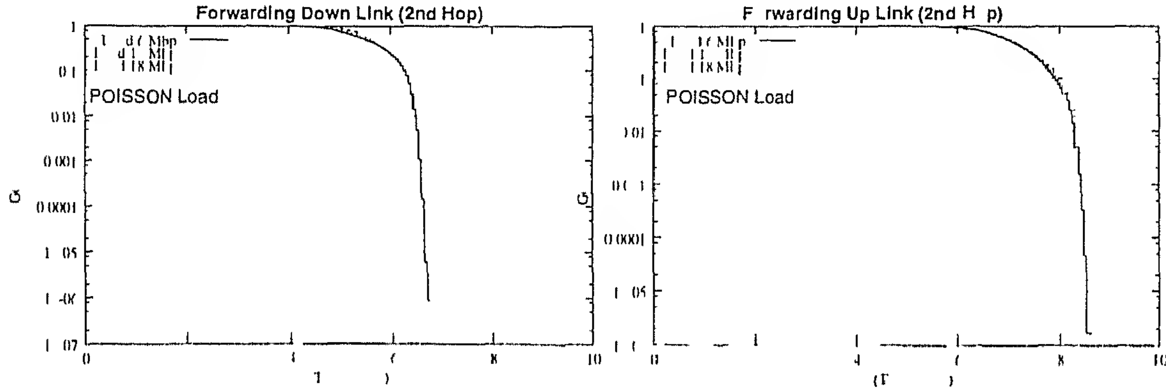


Figure 7.26 Cell delay distribution for 2nd Hop

There is a delay of 2 ms in both the up and the down link cases in addition to the delay for the single hop. This is because the data has to cover an additional hop. A comparison of all the three cases i.e. conventional single hop and two hops is shown in Figure 7.27

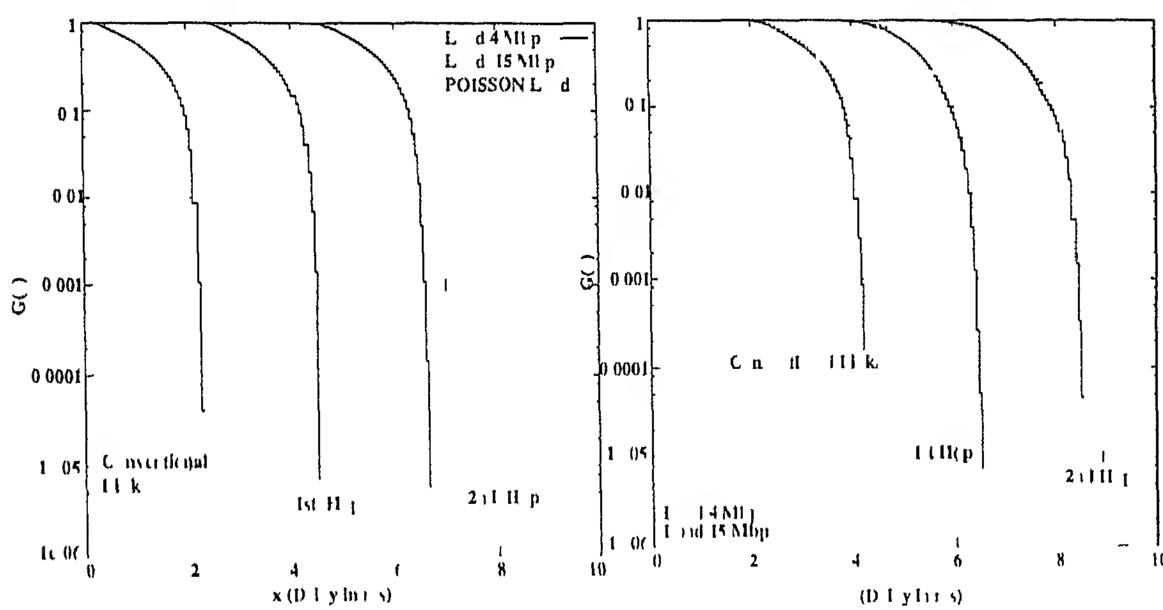


Figure 7.27 Cell delay distribution

Chapter 8

Conclusion and Outlook

In this master thesis the HIPERLAN/2 MAC Protocol was extended to function as a forwarder based on the time sharing concept. The HIPERLAN/2 simulator was revised to include the forwarder and was then analysed for performance evaluation.

8.1 Conclusion

An introduction to the HIPERLAN/2 system was necessary to understand the proposed forwarding concept for the HIPERLAN/2 system. This included the general architecture of HIPERLAN/2 system and its service model. The functionality of each layer of the protocol stack, as given in the HIPERLAN/2 standard, was explained. The implemented HIPERLAN/2 simulator was developed in SDL. A short introduction to this developing language and its developing tool (SDT) was presented. The simulator is modular in construction with each layer or sublayer being represented by seperate block/sub block. An overall picture of the simulator structure and the traffic flow has been presented in Appendix A.

There were multiple options available to implement a forwarder in HIPERLAN/2 such as frequency based, time based and a combination of frequency and time based. All these options were looked into. The major constraints in choosing and option was the compatibility of the implemented forwarder with that of the existing HIPERLAN/2 simulator. Keeping in view the HIPERLAN/2 Specifications of an AP and a MT and the compatibility restrictions the time based forwarding was chosen. The implementation included the revision of the simulator to include a forwarder. Besides implementing a forwarder some modifications were also done in the AP and the MT. Both were made compliant to the latest HIPERLAN/2 Specifications. The system was improved upon by inclusion of better tools in traffic generator and the Discrete Logarithmic Evaluation (DLRE).

The concept was analysed theoretically and compared to the results obtained from the

simulations done in the simulator. Initially only one hop was considered but later the system was modified for multiple hops. It is seen from the results that there is an additional cell delay of approximately 2 ms (one MAC Frame (MF)) for every forwarding hop. This is as expected because the data has to travel on the additional hop which takes one frame. The mean cell delay can be reduced further but not without sacrificing the dynamic structure of the MF. If it can be ensured that the uplink phase for the RMT is allocated after the uplink phase for the FMT, then the data can be made to cover an extra hop in the same MF. There is reduction in the maximum system throughput with every FMT in the network. This is because of the Forwarding Broadcast (F-BC) phase that has to transmitted again for the associated RMTs. The situation is similar to the one when sectored antennas are used in the network. The BC phase has to be sent seperately in each sector. The situation is much better in the case of one FMT in the network and number of RMTs associated to it. The system was optimised for correct functioning in overload conditions and on an erroneous channel. Theoretical analysis done on the probability of Packet Error Rate (PER) on an erroneous channel showed that the PER is high for the PDUs on the forwarding hop. This is due to their dependance on the PDUs on the conventional link. The PER will increase with every additional hop.

Not withstanding the results, the concept promises mobility supporting advantages like size and weight of terminals as also the implementation within the specifications. The results can be optimised by proper organisational control in the network.

8.2 Outlook

The complete HIPERLAN/2 simulator with all the entities of Physical layer and the DLC layer (RCP, EC and MAC) is in the process of integeration. The first model will be ready by end of 1st quarter of 2000. The forwarder developed in this thesis is to be integrated in this first model. Though detailed simulations have been done for the first hop, the 2nd hop has to be further investigated. The concept at present is dependant upon the resources granted for forwarding by the AP. This can either be made independent of this constraint or a better scheduling scheme based on QoS. The latest specifications highlight a procedure to reserve a fixed resource grant for a MT for continuous frames. This can be utilised to optimise the resource granting for the forwarder. Some additional RLC support has to be build into the forwarder. This includes association and disassociation processes, monitoring of link capability, handover between two FMTs or switching over to a direct communication with the AP. Connection admission control can make the system to function

smoothly in overload conditions. It has to be investigated what happens if a RMT moves into the acceptable communication range of the AP. The RMT will receive two BC phases in such a situation. It can be negotiated by coordination in time. The characteristic of the HIPERLAN/2 system to work on only one frequency in a radio cell at any given time and the central control by the AP ruled out the possibility to develop forwarder based on the other two concepts mentioned in the conclusion. Thus time based forwarder was the only option available at this initial stages of development of HIPERLAN/2. Other options based on a combination of frequency and time and also the space domain can be looked into at the later stages.

Appendix A

Traffic Flow in HIPERLAN/2 Simulator

An overall picture of the HIPERLAN/2 Simulator has been presented in this appendix. Figure A shows the simulator structure of the forwarder (FMT) at the block level. Two distinct paths pertaining to the flow of traffic in the uplink and the downlink are shown. In the downlink phase, the FMT physical layer picks up the data and forwards it to the MAC layer. Distinction between data meant for the FMT and data belonging to other MTs is done in the MAC layer. It also accepts data for pertaining to the RMTs associated to it. After accepting the data, two paths are followed depending upon the destination. Data cells meant for own higher layers are sent to the Error Control and data that has to be forwarded to the RMTs is sent to the Forwarder where it is stored temporarily in queues. This stored data is forwarded to the RMTs during the appropriate time in the MAC Sub Frame (SF). Similar path is followed by the up link traffic.

The function of the Scheduler is to manage resources and construct the SF. It evaluates the Resource Request (RR) from the RMTs, adds own RR to it and sends this combined RR to the AP.

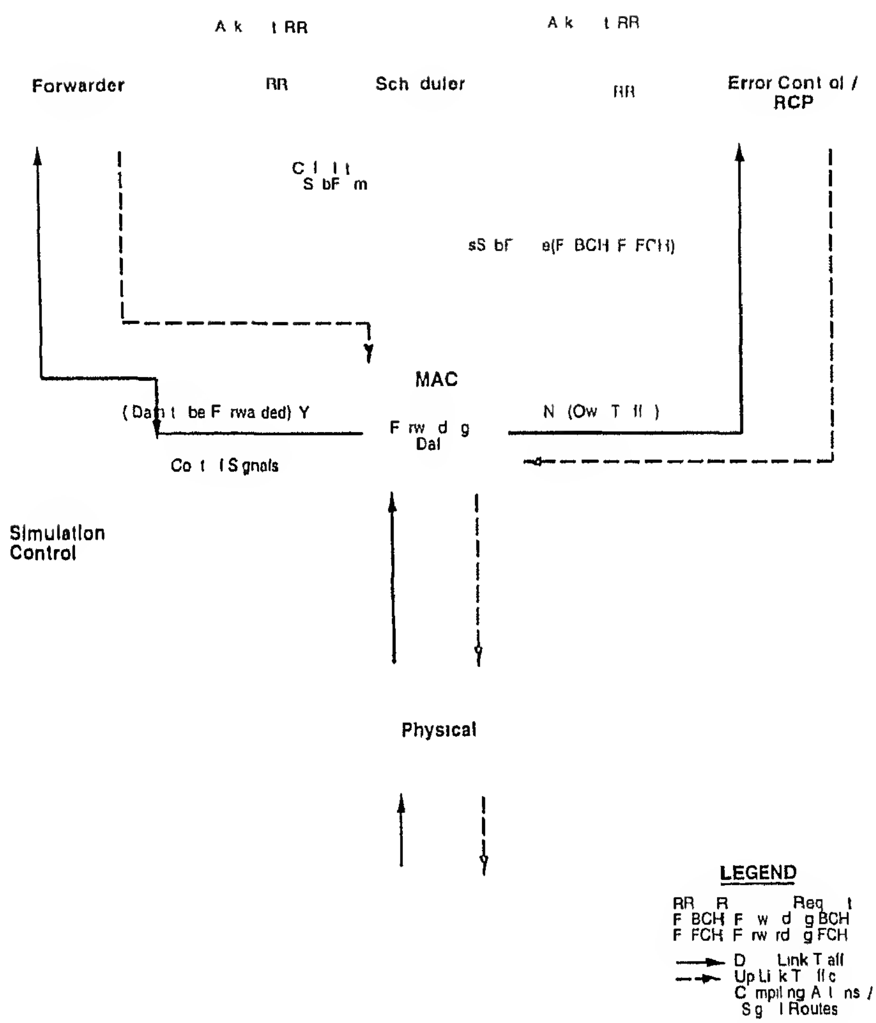


Figure A 1 Traffic flow in HIPERLAN/2 Simulator

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